NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A COST ESTIMATION OF BIOFUELS FOR NAVAL AVIATION: BUDGETING FOR THE GREAT GREEN FLEET

by

Michael D. Callahan

December 2011

Thesis Advisor:	Daniel Nussbaum
Thesis Co-Advisor:	John Mutty

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704–0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202–4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704–0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2011	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE A Cost Estimation of Biofuels for Naval Aviation: Budgeting for the Great Green Fleet			**5. FUNDING NUMBERS**
6. AUTHOR(S) Michael D. Callahan			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943–5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ______N/A______.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

This thesis estimates the cost of biofuel to meet the Department of the Navy's (DON) stated energy objectives, i.e., sailing the Great Green Fleet in 2016 and transitioning to 50 percent alternative fuel by 2020. The first estimate is for the additional cost to operate the Carrier Air Wing (CVW) component of the Great Green Fleet in 2016. A premium to the cost of JP-5 is estimated. A second estimate is made for a CVW operating a six-month deployment with 50 percent biofuel in 2020. A premium was estimated and a sensitivity analysis was conducted to project the required reduction in costs for biofuel from 2012 estimates to reach parity pricing with petroleum fuel by 2020.

14. SUBJECT TERMS Biofuel, Alternative Fuel, Great Green Fleet, Cost Estimation, Naval Aviation, Petroleum, JP-5, Drop-in Replacement Biofuels			**15. NUMBER OF PAGES** 79
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540–01–280–5500

Standard Form 298 (Rev. 2–89)
Prescribed by ANSI Std. 239–18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

A COST ESTIMATION OF BIOFUELS FOR NAVAL AVIATION: BUDGETING FOR THE GREAT GREEN FLEET

Michael D. Callahan
Commander, United States Navy
B.S., United States Naval Academy, 1991

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

from the

NAVAL POSTGRADUATE SCHOOL
December 2011

Author: ______________________________
Michael Callahan

Approved by: ______________________________
Daniel Nussbaum
Thesis Advisor

____
John Mutty
Thesis Co-Advisor

____
William Gates
Dean, Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This thesis estimates the cost of biofuel to meet the Department of the Navy's (DON) stated energy objectives, i.e., sailing the Great Green Fleet in 2016 and transitioning to 50 percent alternative fuel by 2020. The first estimate is for the additional cost to operate the Carrier Air Wing (CVW) component of the Great Green Fleet in 2016. A premium to the cost of JP-5 is estimated. A second estimate is made for a CVW operating a six-month deployment with 50 percent biofuel in 2020. A premium was estimated and a sensitivity analysis was conducted to project the required reduction in costs for biofuel from 2012 estimates to reach parity pricing with petroleum fuel by 2020.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I. INTRODUCTION 1
- **A. OBJECTIVE 1**
- **B. BACKGROUND 1**
  - **1. National Security Strategy 1**
  - **2. Congress 3**
  - **3. Secretary of the Navy 4**
- **C. NAVY BIOFUEL RESEARCH, DEVELOPMENT TEST AND EVALUATION 5**
- **D. UNITED STATES PETROLEUM USE AND SOURCES 6**
  - **1. DoD and DON Petroleum Use 8**
  - **2. Cost Volatility of Petroleum 9**

II. LITERATURE REVIEW 13
- **A. NEAR-TERM FEASIBILITY OF ALTERNATIVE JET FUELS 13**
- **B. ALTERNATIVE FUELS: HOW CAN AVIATION CROSS THE "VALLEY OF DEATH" 14**
- **C. ALTERNATIVE FUELS FOR MILITARY APPLICATIONS 16**
- **D. A TECHNO-ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF HYDROPROCESSED RENEWABLE DISTILLATE FUELS 17**
- **E. DROP-IN REPLACEMENT BIOFUELS: MEETING THE CHALLENGE 17**

III. METHODOLOGY 19
- **A. APPROACH 19**
  - **1. Great Green Fleet 19**
  - **2. Cost of JP-5 .... 20**
    - ***a. Fueling the Carrier Air Wing Today 20***
    - ***b. Transition to Biofuel Blends 21***
  - **3. Biofuel Production Methods 22**
    - ***a. Fischer-Tropsch (FT) 24***
    - ***b. Hydro-Treated Renewable Jet 26***
    - ***c. Direct Synthesis Algal 27***
  - **4. Fueling the Green Fleet 28**
  - **5. A Cost Estimate of Biofuel 30**

IV. DATA AND ANALYSIS 31
- **A. ESTIMATING THE COST OF BIOFUEL 31**
  - **1. Biofuel Test to Production 31**
  - **2. Economic Factors 32**
    - ***a. Biofuel Supply 32***
    - ***b. Biofuel Demand 36***
    - ***c. Supply and Demand Assumptions 38***
  - **3. Projected Cost of Biofuel 38**

B. BIOFUEL COST COMPARISON TO JP-5 41
1. Premium for Blended Gallon 42
2. The Premium for CVW Operations 43
a. Great Green Fleet 46
b. 50 Percent Biofuel in 2020 46
C. FORCES ON THE PRICE OF BIOFUEL 47
1. Quantity Discounts 48
2. Efficiency Improvements 48
3. Inflation 49
4. Sensitivity Analysis 49
V. CONCLUSIONS AND FURTHER STUDY 53
A. CONCLUSIONS 53
B. AREAS FOR FURTHER RESEARCH 53
APPENDIX 55
LIST OF REFERENCES 57
INITIAL DISTRIBUTION LIST 61

LIST OF FIGURES

Figure 1. Alternative Energy Supports National Security (From Harrison, 2008) 3
Figure 2. United States Petroleum Consumption, Production, and Import Trends (1949–2010) (From EIA, 2011) 7
Figure 3. Net Imports and Domestic Petroleum as Shares of U.S. Demand, 2010 (From EIA, 2011) 7
Figure 4. Sources of U.S. Net Petroleum Imports, 2010 (From EIA, 2011) 8
Figure 5. DON Petroleum Consumption in Perspective (From Cullom, 2011) 9
Figure 6. Oil Price Volatility and Trend, 1996–2010 (From Cullom, 2011) 10
Figure 7. Standard Price (TY $) of JP-5, FY 1999–2012 (Data from DLA-E, 2011) 10
Figure 8. Pathways for Biomass to Liquid Fuels Production (From Gorin, 2010) 23
Figure 9. Simplified Process Schematic for Fischer-Tropsch Liquids Production Showing Alternative Feedstocks and Fuel Products (From Bartis & Van Bibber) 25
Figure 10. Life Cycle Greenhouse Gas (GHG) Emissions of Selected Fuels (From Griffith, 2011) 26
Figure 11. Simplified Hydroprossing Renewable Oils System Design (From Pearlson, 2011) 27
Figure 12. Alternative Fuel Production Pathways (From Griffith, 2011) 28
Figure 13. U.S. Navy's Projection of Alternative Tactical Fuel Requirement Afloat to Meet 50 percent goal (From Cullom, 2011) 29
Figure 14. Total Projected Combined DoD and Commercial Demand for Alternative Jet Fuel, DoD Demand for Alternative Marine Diesel, and Total Combined Supply of Alternative Jet & Marine Diesel Fuel from 2012–2028 (From Griffith, 2011) 33
Figure 15. Percentage Of Each Listed Production Method's Contribution to Total Annual Volume of Biofuel in The United States from 2012 to 2028. Data Taken from Griffith, 2011 35
Figure 16. Comparison of DoD Demand for Renewable Jet Fuels and the Projected Supply of these Drop-in Fuels, 2010–20 (From DoD and DLA, 2011) 36
Figure 17. U.S. Navy Biofuel Requirements 2012 to 2020 (From NAVSUP-Energy, 2011) 37
Figure 18. Projected Premium and (Discount) on 50/50 Blended Fuel in Focus Years for Single Fuel Load of 3.3Mgal on CVN 46
Figure 19. Projected Total Premium for 50/50 Blended Fuel During a 6 month CVW Deployment 47
Figure 20. Projected Cost Per Gallon of Biofuel under the Pessimistic Scenario 50
Figure 21. Projected Cost Per Gallon of Biofuel under the Optimistic Scenario 50
Figure 22. Projected Cost Per Gallon of Biofuel under the Likely Scenario 51

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1. Volume, Weight and Cost of JP-5 on CVN..20
Table 2. CVW Daily Use (lbs) and Cost of JP-5 21
Table 3. HRJ Biofuel Quantities and Cost Purchased in 2009 and 2010 and Used for Test and Evaluation Flights by USN and USAF (After Binder, 2011).....32
Table 4. Projected Total Biofuel Production by Year and Method, 2012–2028 (Mgal/yr) (After Griffith, 2011)..34
Table 5. DoD Total Tactical Renewable Fuel Consumption by Year (Mgal) (From DoD and DLA, 2011) 37
Table 6. Forecasted Average Premium per Gallon of “neat” Biofuel Fuel based on Planned Suppliers of Middle Distillate Alternative Fuels. Data from Griffith (2011)..40
Table 7. Forecasted Average Premium or (Discount) per Gallon of Biofuel when Compared to the Projected Cost of JP-5. Biofuel Data from Griffith (2011)..42
Table 8. Projected Premium or (Discount) for each Gallon of Blended 50/50 Fuel. Biofuel Data from Griffith (2011) 43
Table 9. Projected Premium or (Discount) for each Gallon of Blended 50/50 fuel for Focus Years 44
Table 10. Projected Costs for a Full Fuel Capacity of 3.3 Mgal on a CVN for the Focus Years. JP-5 on the Left and a 50/50 JP-5/Biofuel Blend on the Right for Each Scenario. 45

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

BCa	Business Case Assessment
CC	Carbon Capture
CG	Cruiser
CO_2	Carbon Dioxide
CVN	Aircraft Carrier Nuclear
CVW	Carrier Air Wing
DASN	Deputy Assistant Secretary of the Navy
DDG	Guided Missile Destroyer
DLA	Defense Logistics Agency
DLA-E	Defense Logistics Agency – Energy
DORRA	DLA Operations Research and Resource Analysis
DWCF	Defense Working Capital Fund
DoD	Department of Defense
DOE	Department of Energy
DON	Department of the Navy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FT	Fischer-Tropsch
FY	Fiscal Year
GHG	Greenhouse Gas
HRJ	Hydro-treated Renewable Jet
HRO	Hydroprocessed Renewable Oil
IATA	International Air Transportation Association
JP	Jet Propellant
MIT	Massachusetts Institute of Technology
MMbd	Million barrels per day
NAVAIR	Naval Air Systems Command

NAVSUP	Naval Supply Systems Command
NSS	National Security Strategy
O&M	Operations and Maintenance
PARTNER	Partnership for Air Transportation Noise and Emission Reduction
RAND	Research and Development Corporation
RDT&E	Research, Development, Test & Evaluation
SECNAV	Secretary of the Navy
SSN	Submarine – Nuclear
TY	Then Year
USAF	United States Air Force

ACKNOWLEDGMENTS

My sincere appreciation goes to my advisors Dr. Dan Nussbaum and Prof John Mutty. Thank you for your patience with my learning curve on this subject. Your questions always pointed me in the right direction.

Thank you also to the many people who helped with my research including fellow aviators LT Damian “HEFE” Blazy, CDR Stephan “Xman” Xaudaro and CDR David “Deke” Slayton. Thank you to all at DLA Energy for your assistance, especially Ms. Lynda Turner, Ms. Jeanne Binder and Capt Paul Griffith, USAF.

Lastly, to my wife, Rachael, and our children, Jowen, Riona and Reeve, thank you for supporting me with this thesis and course. I could not have completed this without you. I love you, you are a part of me and my everlasting memories.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. OBJECTIVE

Develop a cost estimate for biofuel* used for the Carrier Air Wing (CVW) component of the Great Green Fleet to be deployed by the U. S. Navy in 2016.

B. BACKGROUND

The Department of the Navy (DON) is leading the Department of Defense (DoD) efforts to transition from petroleum based fuels to alternative biofuels used for ships and aircraft. Biofuel may be part of the solution to the problem of dependence on foreign oil for the United States. Under current aircraft engine technology, manned aircraft require a liquid fuel and cannot use hybrid electric or other known alternative energy sources to power aircraft engines. This thesis examined the cost of the biofuel option for Naval Aviation, including when that option might be affordable.

1. National Security Strategy

President Obama's National Security Strategy (NSS) released in May 2010 recognizes U.S. dependence on foreign fossil fuel imports as a threat to economic and environmental security. The 2010 NSS called for the transformation of the U.S. Energy Economy with the goal of leading the world in energy development.

> The United States has a window of opportunity to lead in the development of clean energy technology. If successful, the United States will lead in this new Industrial Revolution in clean energy that will be a major contributor to our economic prosperity. If we do not develop the policies that encourage the private sector to seize the opportunity, the United States will fall behind and increasingly become an importer of these new energy technologies.
>
> We have already made the largest investment in clean energy in history, but there is much more to do to build on this foundation. We must

* Biofuel - Any solid, liquid, or gaseous fuel produced from organic (once-living) matter. The word biofuel covers a wide range of products, some of which are commercially available today, and some of which are still in research and development (Biofuels International, 2011).

> continue to transform our energy economy, leveraging private capital to accelerate deployment of clean energy technologies that will cut greenhouse gas emissions, improve energy efficiency, increase use of renewable and nuclear power, reduce the dependence of vehicles on oil, and diversify energy sources and suppliers. We will invest in research and next-generation technology, modernize the way we distribute electricity, and encourage the usage of transitional fuels, while moving towards clean energy produced at home. (NSS, 2010, p. 30)

President Obama further stated a vision for the United States to develop a new clean energy industry in the "Blueprint for a Secure Energy Future," released by the White House on March 30, 2011, stating:

> We cannot keep going from shock to trance on the issue of energy security, rushing to propose action when gas prices rise, then hitting the snooze button when they fall again. The United States of America cannot afford to bet our long-term prosperity and security on a resource that will eventually run out. Not anymore. Not when the cost to our economy, our country, and our planet is so high. Not when your generation needs us to get this right. It is time to do what we can to secure our energy future. (p. 3)

The "Blueprint for a Secure Energy Future" outlines a three part strategy to help reach these goals as:

> Develop and Secure America's Energy Supplies: We need to deploy American assets, innovation, and technology so that we can safely and responsibly develop more energy here at home and be a leader in the global energy economy.
>
> Provide Consumers With Choices to Reduce Costs and Save Energy: Volatile gasoline prices reinforce the need for innovation that will make it easier and more affordable for consumers to buy more advanced and fuel-efficient vehicles, use alternative means of transportation, weatherize their homes and workplaces, and in doing so, save money and protect the environment. These measures help families' pocketbooks, reduce our dependence on finite energy sources and help create jobs here in the United States.
>
> Innovate our Way to a Clean Energy Future: Leading the world in clean energy is critical to strengthening the American economy and winning the future. We can get there by creating markets for innovative clean technologies that are ready to deploy, and by funding cutting-edge research to produce the next generation of technologies. And as new,

> better, and more efficient technologies hit the market, the Federal government needs to put words into action and lead by example. (The White House, 2011, p. 4)

Figure 1 illustrates how alternative energy development can support United States' National Security, Energy Security and Environmental Security.

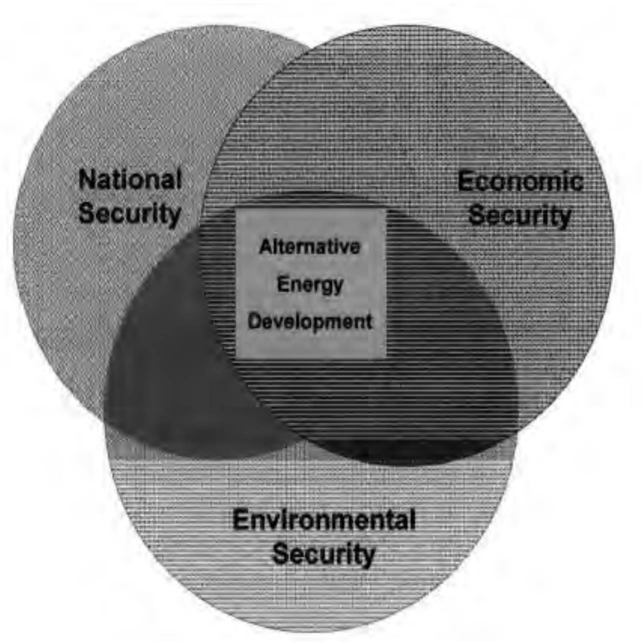


Figure 1. Alternative Energy Supports National Security (From Harrison, 2008)

2. Congress

The Duncan Hunter National Defense Authorization Act for Fiscal Year 2009 called for further research into the use of alternative fuels. Congress directed the Department of Defense to conduct a study aimed at "reducing life cycle greenhouse gas emissions; and (reviewing) the goals and the progress of the military departments in the research, testing and certification of alternative fuels" (RAND, 2011). The law authorizes "The military utility of domestically-produced alternative and synthetic fuels for military operations and for use by expeditionary forces" (Congress, 2009).

3. Secretary of the Navy

In 2009, Secretary of the Navy (SECNAV), Ray Mabus, set energy goals for the Navy in a speech to the Navy Energy Forum. He stipulated five specific targets:

- The lifetime energy cost of a building or a system, and the fully burdened cost of fuel will be mandatory evaluation factors for awarding future acquisition contracts.
- By 2016, the Navy will sail a Strike Group as a Great Green Fleet composed of nuclear ships, surface combatants equipped with hybrid electric alternative power systems running biofuel, and aircraft flying only biofuels – and we will deploy it.
- The DON will, by 2015, reduce petroleum use in our 50,000 strong commercial car fleet in half.
- The DON will, by 2020, produce at least half of our shore based energy requirements on our installations from alternative sources.
- By 2020, half of our total energy consumption for ships, aircraft, tanks, vehicles and shore installations will come from alternative sources. (Mabus, 2009)

The DoD uses 93 percent of all energy within the federal government, which equates to two percent of all energy used within the United States (Cullom, 2011). Secretary Mabus noted in many speeches that the Navy historically leads energy change, from the shift from wind to coal, then coal to oil and more recently from oil to nuclear power.

This thesis focuses on developing cost estimates associated with two of the five goals above: Deployment of the Great Green Fleet by 2016 and switching to 50 percent consumption of alternative fuels by 2020. In an August 2011 talk at the Naval Postgraduate School, Secretary Mabus further emphasized the push toward alternative fuels to include drop-in replaceable biofuels for aviation.

Drop-in replaceable fuels are second generation biofuels which can be blended up to 50 percent with petroleum jet fuels and be considered functionally equivalent end fuel. Drop-in replacement biofuels require no change to the aircraft engine or supply chain infrastructure. All biofuels being researched and tested by the DON are drop-in replaceable.

The stated long term goal is energy independence and security for the United States. "Energy Security is National Security," Mabus repeated multiple times in his August 2011 speech. In building this energy independence and security, he recognized the dependence on global solutions through allies and industry.

The DoD and the DON are creating an initial demand for biofuels through purchase contracts and research, development, test and evaluation (RDT&E). Future growth in the biofuel industry may be able to meet growing demand within the DoD and increase scale for use in the commercial aviation industry.

C. NAVY BIOFUEL RESEARCH, DEVELOPMENT TEST AND EVALUATION

Clean energy technology includes multiple alternatives, such as solar, hybrid electric and nuclear as well as alternatives to fossil fuels, including the development of aviation biofuels. Many of these biofuels are being produced from non-edible biomass grown on marginal lands and coastal waters. Some are produced using coal to liquid technology. These may be the fuels of the future and, in the near term, will be blended with petroleum based fuels such as Jet Propellant (JP)-5 to power the engines and aircraft of today. Alternative fuels must be drop-in replaceable for JP-5. Drop-in replaceable fuels provide the same aircraft engine performance as 100 percent JP-5 with no engine modifications. Currently, the fuels are blended at a maximum of 50/50 ratio.

Drop-in biofuels are undergoing developmental testing in multiple U.S. Naval aircraft. As of September 2011, the following eight naval aircraft had been successfully flown on a 50/50 blend of JP-5 and a camelina based biofuel (NAVAIR, 2011):

- F/A-18D Hornet
- F/A-18 E/F Super Hornet
- MV-22 Osprey
- H-60S Sea Hawk
- T-45 Goshawk
- EA-6B Prowler
- AV-8B Harrier
- MQ-8B Fire Scout

The Navy's plan is that in 2012, an operational test of these aircraft flying on a 50/50 blend of JP-5 and biofuel will be conducted as a Green Strike Group. With further development of this technology, the Navy will deploy this strike group by 2016 as part of the Great Green Fleet, including the CVW fueled with a biofuel blend. The Navy intends to operate all aircraft on biofuels for the first portion of this deployment. For the CVW, this fuel is drop-in replaceable biofuel blended at a 50/50 mix with JP-5, the Navy's ship petroleum based jet fuel. As Rear Admiral Phil Cullom, Director of the Navy Energy and Environmental Readiness Division, stated, "Our commitment to the aggressive test schedule for drop-in replacement fuels for JP-5 … keeps us on pace for the 2012 demonstration and 2016 deployment of the Great Green Fleet" (NAVAIR P. A., 2011).

The DoD and DON are contracting with domestic biofuel companies to purchase the fuel used during test and development of aircraft. Replacing 50 percent of the petroleum consumed by the DON with domestically produced biofuel, may reduce the amount of imported petroleum. This, in turn, could reduce U.S. dependence on politically unstable regions and improve U.S. national security and energy security.

D. UNITED STATES PETROLEUM USE AND SOURCES

As stated in the National Security Strategy of 2010, energy independence and energy security are key goals of U.S. National Security. As the Secretary of the Navy has said,

> It's all about our energy security and moving toward complete energy independence. Our military and our country rely too much on fossil fuel. That dependency degrades our national security; it also harms the environment and has a negative effect on our economy. (Mabus, 2011)

Figure 2 shows U.S. petroleum consumption, production and net imports. Close examination of the chart reveals that net imports increased at a faster rate than consumption from 1985 to the peak in 2005.

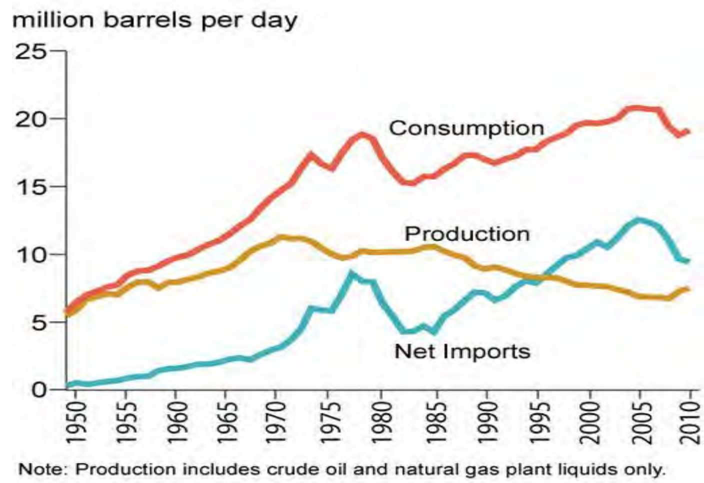


Figure 2. United States Petroleum Consumption, Production, and Import Trends (1949–2010) (From EIA, 2011)

In 2010, the U.S. consumed 19.1 million barrels per day (MMbd) of petroleum products. This is approximately 22 percent of total world consumption. U.S. net imports of petroleum in 2010 were approximately 9.4 MMbd; this was 49 percent of consumption, as seen in Figure 3 (EIA, 2011).

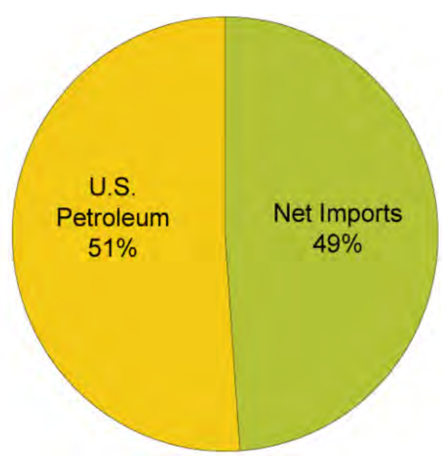


Figure 3. Net Imports and Domestic Petroleum as Shares of U.S. Demand, 2010 (From EIA, 2011)

The 51 percent of U.S. petroleum was made up of 5.5 MMbd of crude oil production and 4.2 MMbd gained from expansion of crude oil in the refining process,

liquid fuel captured during natural gas processing and other sources of liquid fuel, including biofuels. Figure 4 shows the regions from which the U.S. imported petroleum, 41 percent came from geographically distant or politically unstable regions (EIA, 2011).

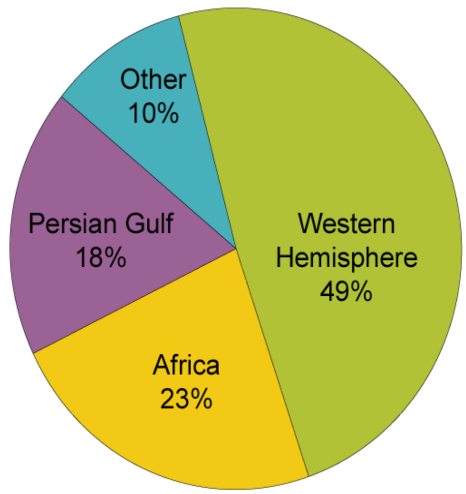


Figure 4. Sources of U.S. Net Petroleum Imports, 2010 (From EIA, 2011)

U.S. imports of petroleum peaked in 2005 at 10.1 MMbd. Imports have declined in each of the last five years, as has consumption. These declines have been credited to "improvements in efficiency, changes in consumer behavior and patterns of economic growth. At the same time, increased use of domestic biofuels (ethanol and biodiesel)…expanded domestic supplies and reduced the need for imports" (EIA, 2011).

1. DoD and DON Petroleum Use

Figure 5 shows that the U.S. federal government uses about 2 percent of total U.S. petroleum consumption. The DoD uses 93 percent of that amount, and the DON then uses 25 percent of total DoD consumption. In 2008, the DON total consumption was 29,000,000 barrels and Naval Aviation consumed 41 percent of this, approximately 11.9 M bbls in FY08.

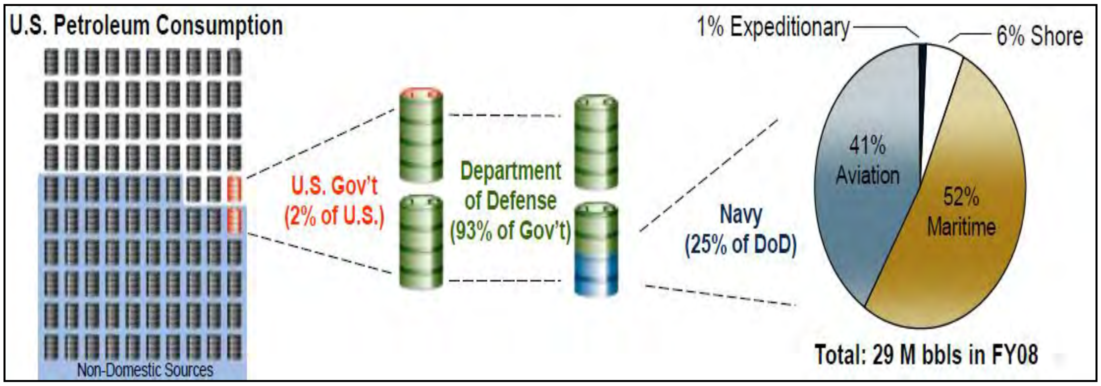


Figure 5. DON Petroleum Consumption in Perspective (From Cullom, 2011)

2. Cost Volatility of Petroleum

Through the Defense Logistics Agency Energy (DLA-E), DoD budgets for the cost of fuel using a set standard price, defined by DLA-E as:

> The standard price of fuel is a tool that was created by DoD's fiscal managers to insulate the Military Services from the normal ups and downs of the fuel marketplace. It provides the Military Services and OSD with budget stability despite the commodity market swings, with gains or losses being absorbed by a revolving fund known as the Defense Working Capital Fund (DWCF). In years that the market price of fuel is higher than the standard price, the DWCF loses money. In years that the market price is lower than the standard price, it makes money. This gain or loss can be made up by adjusting future standard prices or by providing our DoD customers with a refund. This decision is typically made by the Office of the Secretary of Defense, Comptroller. However, the DWCF must remain cash solvent. As a result, in rare instances such as fiscal year 05, the standard price is changed during the fiscal year so the fund remains solvent. (DLA-E, 2011)

Figure 6 shows the volatility of oil prices from 1996 through 2010. The trend line in the figure also indicates a steady rise in the price of oil over the same period. Uncertainty and increasing costs of energy affects everyone's operating expenses.

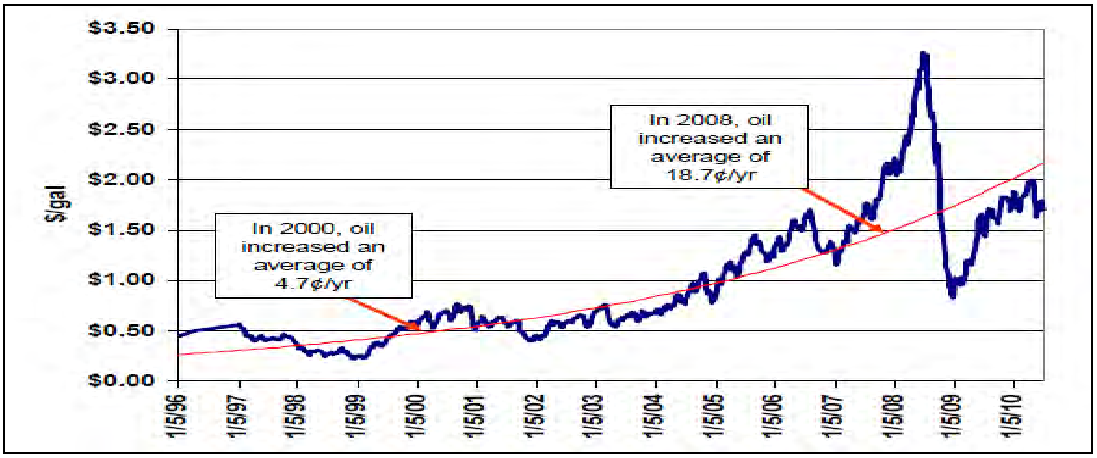


Figure 6. Oil Price Volatility and Trend, 1996–2010 (From Cullom, 2011)

Figure 7 shows the standard price of JP-5, in Then Year (TY) dollars, as set by DLA-E from 1999 through 2012. Although DLA-E set the price of fuel in advance, there were multiple changes which followed the volatility in the market price of oil. The standard price of JP-5 was changed four times in FY2009 alone. Again the trend line shows an increase of the price of JP-5 from a low of $0.63 per gallon in FY2000 to the current price of $3.97 per gallon for FY2012.

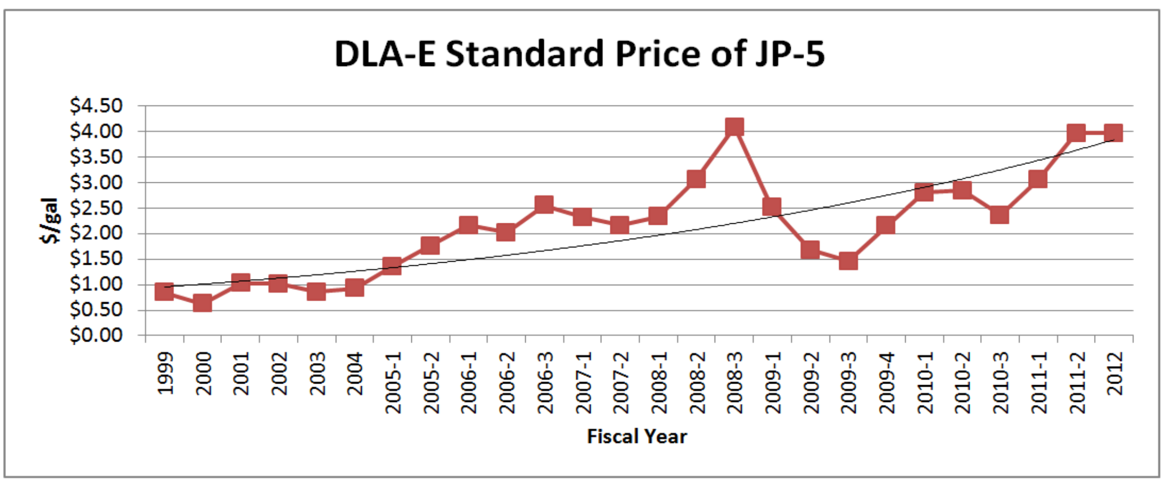


Figure 7. Standard Price (TY $) of JP-5, FY 1999–2012 (Data from DLA-E, 2011)

The volatility of the standard price of JP-5 can affect the readiness of aviation squadrons. Increases in the standard price of JP-5 may reduce the amount of hours flown. That is, pilots spend less time in the air training for the same cost of fuel, with a risk that readiness can deteriorate.

With the upward trend of the standard price, overall Operations and Maintenance (O&M) budgets are affected. As a 2009 Congressional Research Report stated: "In FY2000, fuel costs represented 1.2 percent of the total DoD spending, but by FY2008 fuel costs had risen to 3.0 percent. Over the same time, total defense spending had more than doubled, but fuel costs increased nearly 500 percent" (Andrews, 2009, p. 2). Reducing and maintaining a steady price of fuel may help the DoD control the O&M budget.

THIS PAGE INTENTIONALLY LEFT BLANK

II. LITERATURE REVIEW

Multiple studies have been published about biofuels and their use in military and commercial aviation. At the direction of the Hunter Defense Authorization Act of 2009, Research and Development Corporation (RAND) published a report on biofuels entitled "Alternative Fuels for Military Applications." A joint report was released by RAND and Massachusetts Institute of Technology (MIT) in 2009 titled "Near-Term Feasibility of Alternative Jet Fuels." Over the past three years, multiple MIT theses have been published on the subject. Summary descriptions of these are provided.

A. NEAR-TERM FEASIBILITY OF ALTERNATIVE JET FUELS

Joint report with MIT and RAND, 2009:

This technical report was sponsored by the Federal Aviation Administration, with the research performed jointly by MIT's Partnership for Air Transportation Noise and Emission Reduction (PARTNER) and the Environment, Energy and Economic Development Program within RAND. The report focused on "alternative jet fuels that could be available commercially in the next decade using primarily North American resources" (Hileman et al., 2009, p. iii).

The authors examined the alternative fuels which would likely be commercially available within the next ten years for use as aviation fuel, and which come from one of five sources:

- Conventional petroleum
- Unconventional petroleum
- Fischer-Tropsch (FT) indirect liquefaction process
- Renewable oils from biomass, and
- Alcohols from fermentation of biomass (Hileman et al., 2009, p. 11)

The report concludes that none of the alternative fuels "that can be available in large quantities offers sufficient price or environmental benefits to aviation to warrant major changes in the infrastructure for at least the next decade" (Hileman et al., 2009, p. 64).

B. ALTERNATIVE FUELS: HOW CAN AVIATION CROSS THE "VALLEY OF DEATH"

William E Harrison III – MIT Thesis, 2008:

The "Valley of Death" describes the difficulty of transitioning a new technology or industry from the research and development phase to production. Without sufficient capital many technologies and industries fail to make the transition. A 2008 thesis examines "the barriers and risks associated with the technology adoption life cycle for alternative aviation fuels as viewed through the lenses of the technology developer, the early adopter, the early majority user and the financial community" (Harrison, p. 2). The author makes the following recommendations for aviation to cross the "Valley of Death" for alternative fuel use, as quoted verbatim:

> - The DoD should collaborate with other government agencies to develop the tools and procedures to compare life-cycle-analysis and sustainability criteria such that alternatives can be compared on an equal basis and re-evaluated periodically to allow the determination of long and short-term impacts as each alternative fuel emerges.
> - The DoD should request that Environmental Protection Agency (EPA) and Department of Energy (DOE) develop a clear definition of CO_2 life cycle footprint for petroleum and the boundaries for a well-to-wake calculation of alternative fuels and collaborate with them on alternative fuels analyses.
> - To help the industry cross the "Valley of Death," develop multiple-agency projects that create government and the industry learning for the first-of-a-kind plants utilizing tools to minimize cost and maximize commercial potential. Use the DoD as the knowledgeable buyer and the other agencies as agents facilitate learning about new technologies and the environmental effects. This risk mitigation approach should enable commercial financing of the project and minimal expenditures from the government and allow the industrial partner to focus on business practices and the efficiencies needed for unsubsidized operation. The data from these projects can be used to update the balanced scorecard and risk analysis tools and to assist the government in the future R&D investment and generate support for other alternative fuels projects.

- Open the military and commercial standard architecture to allow the entrance of alternative fuel technologies and build enthusiasm for business to compete against oil. Expand the role of the Commercial Aviation Alternative Fuels Initiative to include guiding a robust R&D program to solve technical challenges, become a data exchange platform for the industry, expand stakeholder networking, and focus on the key elements of fuel cost reduction, environmental stewardship, and safety of flight.
- State and federal governments play an important role in helping first-of-a-kind plants to be built. Government should provide support for sitting and permitting processes, have land use policy in place, and develop comprehensive greenhouse gas and carbon sequestration legislation. This legislation combined with programs to analyze alternative energy projects under the National Environmental Policy Act guidelines and with proper land use policy, can lead to the deployment of next generation fuel technologies that have environmental impact. The military and commercial airlines should qualify and certify the fuels such that they are willing to buy them once the plant is completed.
- The military and commercial airlines should collaborate with state governments that are favorable to the development of alternative energy projects and provide support for the project developers. Alternative aviation fuel projects would provide rural economic development and increase local wealth. Partnerships with the military and the commercial airlines bolster national security and enable strong business commerce.
- The government should develop an effective set of tools such as an expanded loan guarantee program for alternative energy projects and frameworks for long-term market based off-take agreements to help reduce the financial risk of first-of-a-kind plants. These incentives should help provide risk reduction backstops and provide benefits to the government, the developer, and the public.
- The military and the civil community must certify alternative fuels for use in all aircraft, engines and ground infrastructure and become early adopters. The collaborative actions would provide a market for the alternatives and create an early majority of airports and airbases such that it will drive the dynamics of adoption at other locations until demand is satisfied.

> Increasing demand will help the industry grow and be viable and is likely to provide a global leadership for the industry. (Harrison, 2008, pp. 234–237)

The primary conclusion of Harrison's thesis is that by following these recommendations industry and government can create demand for alternative aviation fuels. Government, through the DoD, can be an early adaptor of the new fuel. An early adaptor might also be an airline or groups of airlines who cluster their demand by location and enter into contracts with producers of biofuel. Contracts for set quantities of biofuel will create certainty for the producer and reduce the market risk by creating a market pull situation. Harrison states that as "an early adaptor…the aviation industry will open the door to additional opportunities and the wisdom of markets will hone the future to the correct set of sustainable products" (Harrison, 2008, p. 182).

C. ALTERNATIVE FUELS FOR MILITARY APPLICATIONS

RAND Report, *2011*:

A 2011 RAND report, directed by the Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, had three objectives:

- Review alternative approaches for reducing greenhouse gas (GHG) emissions
- Examine the military utility of mobile, in-theater synthetic fuel processes
- Review the goals and progress of the military departments in the research, testing, and certification of alternative fuels (Bartis & Van Bibber, 2011, p. iii)

The authors make recommendations to each of the above points:

- Fischer-Tropsch fuels are the most promising near-term options for meeting the Department of Defense's needs cleanly and affordably.
- Concepts for the forward-based alternative fuel production do not offer a military advantage.
- Defense Department goals for alternative fuels in tactical weapon systems should be based on potential benefits, since the use of alternative rather than petroleum-derived fuels offers no direct military benefits.

The authors recommend that the military pursue programs which require more energy efficiency instead of investing in alternative fuels. The authors acknowledge that

their "findings conflict with the views and actions taken by the Department of Defense organizations involved in alternative fuel research, testing, and certification" (Bartis & Van Bibber, 2011, p. xi).

D. A TECHNO-ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF HYDROPROCESSED RENEWABLE DISTILLATE FUELS

Matthew Pearlson - MIT Thesis, *2011*:

Pearlson examines the production side of the biofuels industry and models the "economic costs and environmental impacts of producing fuels from hydroprocessed renewable oils (HRO) process" (Pearlson, 2011, p. 3). Pearlson studies the design and costs of building a refinery for producing biofuels, and he models expenses and revenues to estimate gross income. The costs for such a project involve the capital costs for initial investment and the operating costs for the refinery. These costs vary depending on the size of the refinery; however, at all production sizes studied "the facility is not economically viable" (Pearlson, 2011, p. 69). Additionally, he studies the environmental impact of a refinery from water usage to greenhouse gas emissions.

The author concludes that HRO fuels are a viable alternative fuel source for drop-in replaceable synthetic fuel despite high costs. "It was found that the baseline cost for HRO fuel production ranges between $3.80 and $4.39 per gallon depending on the size of the facility" (Pearlson, 2011, p. 91). The availability of feedstocks for biofuel production and the access to capital for refinery construction are the major hurdles for these fuels making it to market.

E. DROP-IN REPLACEMENT BIOFUELS: MEETING THE CHALLENGE

Alok Bhargava – MIT Thesis, 2011:

Bhargava examines the U.S. Navy's requirement for drop-in replacement biofuels for aviation, as well as public and private funding for this developing industry. The author concludes that the hydroprocessed renewable jet (HRJ) method is the closest fuel production path to achieving the goals for the Navy.

Bhargava recognizes the strategic importance to the United States of creating an alternative energy source; however, private industry and venture capitalists are hesitant to

invest in this nascent industry. He states, “The lack of private sector solutions, scale of the challenge and the national imperative naturally render this task to public policy” (Bhargava, 2011, p. 98). The author makes two recommendations:

1. Public policy efforts must distinguish between newer technologies such as solar and wind power generation that create a fungible product, albeit at a higher cost, that can be sold at a market price, versus many advanced biofuel projects that do not.
2. Given fixed budgets, public policy efforts must carefully allocate funding to direct sufficient capital towards advanced biofuels projects that cannot participate in off-take agreements-based structures or Renewable Portfolio Standards (RPS).

Whereas the technology is capable of converting plant oils into fuel through hydro processing, the cost of this process is currently too high to make it economically feasible. Government investment is crucial to meeting the strategic goal of an alternative to petroleum based fuels.

III. METHODOLOGY

A. APPROACH

The approach taken in this thesis consisted of the following five steps. Details of these steps are discussed in this chapter. All dollar amounts stated are in then year (TY) dollars. Then year dollars are inflation adjusted values used in budgeting for each fiscal year.

1. Define the Great Green Fleet and its air wing
2. Collect data on JP-5 fuel cost and usage for a CVW
3. Examine the current methods used to produce biofuel
4. Collect data for the production level and cost of biofuel
5. Estimate the cost of biofuel at possible future production levels

1. Great Green Fleet

The Great Green Fleet for 2016 is composed of:

- one nuclear Carrier (CVN)
- one nuclear Submarine (SSN)
- one Cruiser (CG)
- two Destroyers (DDG)
- one Air Wing (CVW)

Characteristics of the Great Green Fleet for 2016 are:

- All conventional ships and aircraft will be certified to use biofuel.
- All surface ships will contain a full load out of 50/50 biofuel blend.
- After the initial load out with biofuel, ships will re-fuel with conventional fuel.
- Carrier will contain one full load out of aircraft biofuel.

- Aircraft will initially re-fuel from carrier's stored bio-fuel and will re-fuel with conventional fuel thereafter.

2. Cost of JP-5

For planning and budgeting purposes DoD releases a standard fuel price memo. The memo for Fiscal Year (FY) 2012 was released on September 28, 2011, stating that:

> The composite standard fuel price of $166.74 per barrel implemented on June 1, 2011will remain in effect for FY 2012. The FY 2012 President's Budget fuel standard composite selling price of $131.04 per barrel is too low given the current world crude prices, the crude oil price projections from the NYMEX Commodities Exchange, and the Defense Logistics Agency, Defense-wide Working Capital Fund projected cash position. (Roth, 2011)

Therefore, the budgeted price for JP-5 for FY 2012 is stated as $3.97 per gallon or $166.74 per barrel (Roth, 2011).

a. Fueling the Carrier Air Wing Today

The following tables show the cost of fueling a CVW with conventional JP-5 fuel. These numbers provide the baseline cost of conventional fuel to compare with the cost estimation of biofuel.

Table 1 shows the size and current cost to fill the fuel storage tanks on the Nimitz class aircraft carriers. The cost of JP-5 is generally shown as a per gallon figure. For aircraft, fuel is calculated in pounds. Table 1 show the cost per gallon and cost per pound of fuel. Density of 6.8 lbs/gal is used for the conversion factor.

Fuel Tank Capacity (Mgal)	JP-5 $/gal	Fuel Cost $/tank ($M)	Density JP-5 (Std Day) lb/gal	Fuel Tank Capacity (Mlbs)	JP-5 $/lb
3.3	$3.97	$13.1	6.8	22.44	$0.58

Table 1. Volume, Weight and Cost of JP-5 on CVN

Table 2 shows the typical components of a CVW. The wing is made up of squadrons which fly three variants of F/A-18s (Hornet, Super Hornet and Growler), the E-2 Hawkeye and the SH-60 Sea Hawk.

Daily operations consist of approximately 100 sorties divided among all aircraft. The fuel costs per flight hour of each aircraft flown are calculated using the current cost of JP-5 consumed in pounds per hour flown (Aircraft NATOPS manuals). Fuel burn rate changes with aircraft configuration, drag count and throttle setting. For consistency, the maximum endurance fuel burn rate was used for all cost calculations.

Carrier operations are flown on a cycle time. This allows for the launch of all aircraft separate from recovery operations. One sortie is equal to one flight from launch to recovery. The sortie times are listed in Table 2 for each aircraft type. Total fuel use and costs per day are based on the total hours flown for each aircraft type.

CVW JP-5 Daily Fuel Use and Costs							
Aircraft Type	No. per CVW	Sorties/ Day	Cycle Time Hrs/Sortie	Fuel Burn Rate lbs/hr	Fuel Cost $/hr	Fuel Burn lbs/day	Fuel Cost $/Day
F/A -18 C/D	24	28	1.5	4800	$2,802	201,600	$117,699
F/A -18 E/F	20	27	1.5	6000	$3,503	243,000	$141,869
F/A- 18 G	5	27	1.5	7000	$4,087	283,500	$165,514
E-2D	5	6	4.5	1900	$1,109	51,300	$29,950
SH-60S	14	12	3	900	$525	32,400	$18,916
Totals	**68**	**100**			**$12,027**	**811,800**	**$473,948**

Table 2. CVW Daily Use (lbs) and Cost of JP-5

b. Transition to Biofuel Blends

In the Navy's Energy Strategic Roadmap, issued in 2010, three challenges are identified to achieve the SECNAV's energy goals. Advancements in these areas are critical to this success and are summarized as:

> Technology maturity: Technology continues to mature and the ability of the DON to leverage leading-edge technology and deploy it in tactical and shore arenas is critical. The DON must be able to evaluate new systems and make the right decisions on which technologies to invest in while fully understanding the risks associated with using new approaches. The DON

will continue to work with industry and other partners to build additional market pull to incentivize investments in alternative technologies, energy sources, fuels, and infrastructure.

Resource availability: DON has an opportunity to develop solutions that leverage the financial resources of its government and industry partners. The DON will need to work closely with its partners, exploring all appropriate avenues to fund the investments necessary to meet the SECNAV's goals.

Alternative fuel availability: Although Naval forces consume millions of barrels of petroleum products each year, the DON is not a major market driver and therefore will need to partner with the commercial marketplace to grow a market where alternative fuel is available in sufficient quantities. Major players need to invest in alternative fuel production and infrastructure technologies—the demand for these fuels must come from the commercial marketplace as well as the DON in order to spur investments and drive down costs. Moreover, Naval alternative fuels must be "drop in" replacements, able to mix with traditional petroleum products with no adverse effects to the fuel quality or performance. The DON will continue to test and certify equipment for compatibilities with alternative fuels derived from multiple feedstocks, ensure that alternative fuels utilized have lower life cycle greenhouse gas emissions than conventional petroleum-based fuels, collaborate with industry and government partners to encourage market participation, and increase the amount of alternative fuel available to the commercial and DON markets. (Deputy Assistant Secretary of the Navy, (DASN) Energy Office, 2010)

3. Biofuel Production Methods

The following is a brief summary of some of the methods used to produce biofuels. There are many technical sources available which provide more in-depth details on these processes. The U.S. DOE website, Biomass.Energy.gov, offers more resources and provides a place to start for further research.

There are multiple pathways for biomass conversion to biofuel. The biomass must first be broken down to an oil, sugar or gas form. These then become the input for the refining process. Within these pathways there are different processing methods for refining the oil to fuel, including jet fuel. Figure 8 shows examples of the multiple pathways.

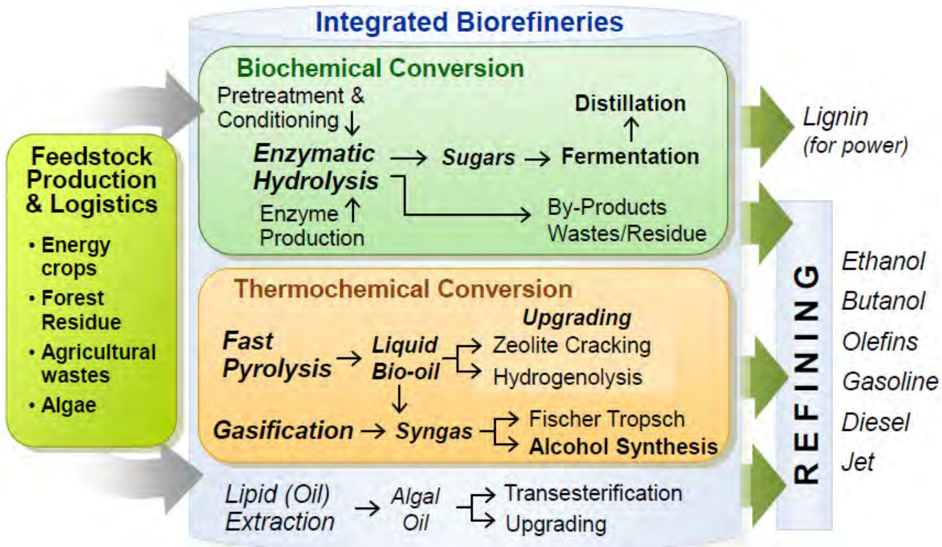


Figure 8. Pathways for Biomass to Liquid Fuels Production (From Gorin, 2010)

These three pathways for converting biomass to biofuel were described in Bhargava's thesis as:

- *Biochemical conversion* produces alcohols such as ethanol and butanol. Sugar cane, corn and cellulosic ethanol are produced using biochemical conversion.
- *Thermochemical conversion* that with the application of heat and other methods, including catalysts, converts biomass to either synthetic gas (also known as syngas) or an intermediate bio-oil. Both syngas and bio-oil can be processed to produce long-chain hydrocarbon fuels including diesel, and natural gas. One such process, Fischer-Tropsch processing, has garnered much interest specifically due to its applicability to coal and natural gas in combination with carbon capture to produce liquid fuels. Syngas can also be processed into alcohols.
- *Lipid processing* that takes as input plant and/or animal oils, fats and greases and converts them to bio-diesel or other long-chain hydrocarbon fuels such as gasoline and jet fuel. There are two main sub-pathways in lipid processing: transesterification and hydroprocessing. (Bhargava, 2011)

The processing methods reviewed in this thesis are:

- Fischer-Tropsch (FT)
- Hydro-treated renewable Jet (HRJ)
- Direct Synthesis Algal

a. Fischer-Tropsch (FT)

This method was developed in the 1920's and is used to convert coal, natural gas, or biomass to liquid fuel. The FT method has been used to produce fuel, including aviation fuel, throughout the twentieth century and is still being used today (Bartis & Van Bibber, 2011).

There are four steps involved in the FT process. Bhargava describes these steps as:

- Creation of synthesis gas: syngas, a mixture of hydrogen and carbon monoxide is created using biomass, coal or natural gas as feedstock. Biomass and/or coal feedstock is reacted with steam at elevated temperatures and moderate pressure to produce syngas. Natural gas is converted to syngas using one of two well established commercial methods: partial oxidation or steam reforming.
- Purification of syngas stream: accomplished by removing CO_2 and small amounts of gaseous compounds derived from impurities e.g. sulfur in the feedstock.

  Gasification of coal and/or biomass results in large concentrations of CO_2. In comparison creating syngas from natural gas generates insignificant amounts of CO_2.
- Fischer-Tropsch synthesis: in this process the syngas is passed over a catalyst under specific process conditions to yield a "broad mixture of hydrocarbons ranging from gases (such as ethane) to waxes (longer hydrocarbons)"; the composition of this mixture can be controlled by altering reaction conditions.
- Refining: the resultant hydrocarbon mixture is then "upgraded to liquid fuels using well established methods in common use in petroleum refineries." (Bhargava, 2011)

Figure 9 shows a simplified schematic of the FT process.

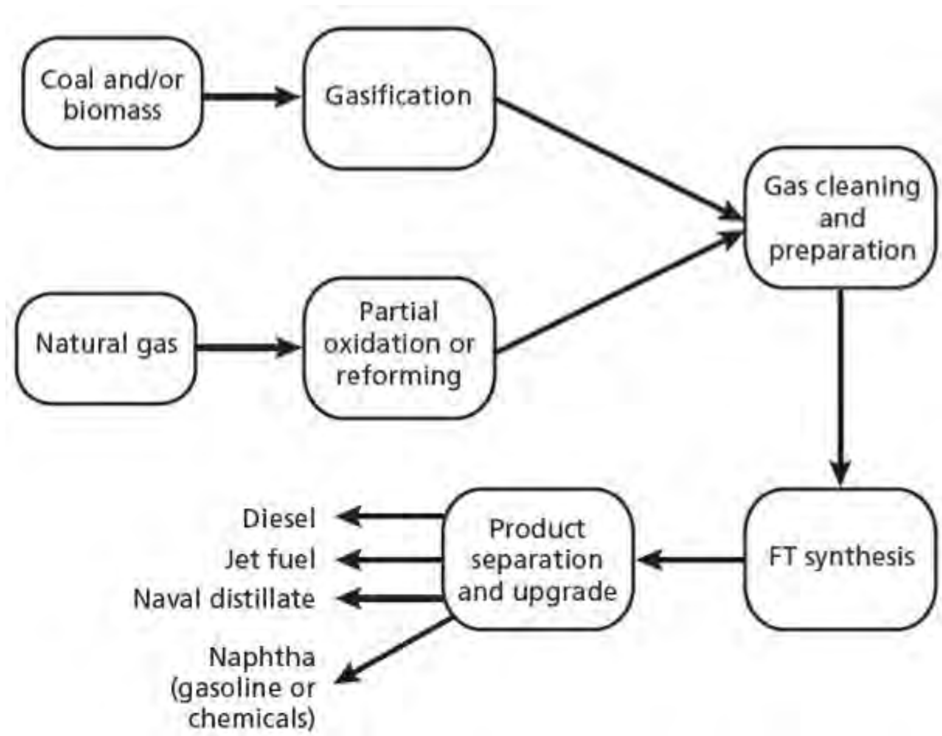


Figure 9. Simplified Process Schematic for Fischer-Tropsch Liquids Production Showing Alternative Feedstocks and Fuel Products (From Bartis & Van Bibber)

Because the traditional FT process releases high CO_2 emissions, the DON is currently not conducting RDT&E with these fuels. Section 526 of the Energy Independence and Security Act of 2007 states:

> No Federal agency shall enter into a contract for procurement of an alternative or synthetic fuel, including a fuel produced from nonconventional petroleum sources, for any mobility-related use, other than for research or testing, unless the contract specifies that the life cycle greenhouse gas emissions associated with the production and combustion of the fuel supplied under the contract must, on an ongoing basis, be less than or equal to such emissions from the equivalent conventional fuel produced from conventional petroleum sources.

However, because carbon capture (CC) technology is advancing, future fuels produced with this method may meet the standards set by this statute. Figure 10 shows the life cycle greenhouse gas (GHG) emissions for each listed fuel. Any fuel with an indicator on or to the left of the traditional fuel line meets the Section 526 mandate.

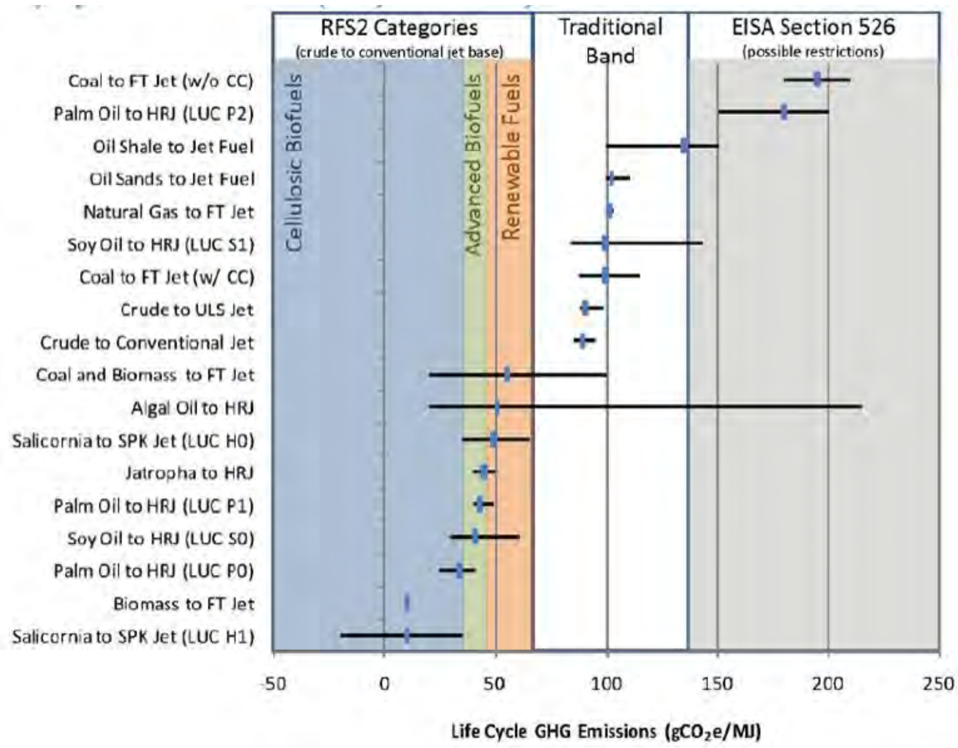


Figure 10. Life Cycle Greenhouse Gas (GHG) Emissions of Selected Fuels (From Griffith, 2011)

b. Hydro-Treated Renewable Jet

Most of the fuel currently tested and certified by the DON is processed via Hydro-Treated Renewable Jet (HRJ). This process takes renewable oils from multiple sources, including pure vegetable oil, pyrolysis oils, animal fats and recycled products (Pearlson, 2011). Pearlson describes the HRJ process as follows:

> The first step uses hydrogen gas and catalyst to saturate double bonds, cleave the propane backbone, and remove oxygen from a feed of oils and fats. The second processing step, known as isomerization and cracking, rearranges and reduces the molecular chain lengths to improve cold weather performance. (Pearlson, 2011)

The resulting fuel is drop-in replaceable, having no adverse affects on aircraft engine performance. These fuels are also lower in GHG emissions than some of the fuels produced by FT process.

Figure 11 shows a simplified hydroprocessing design.

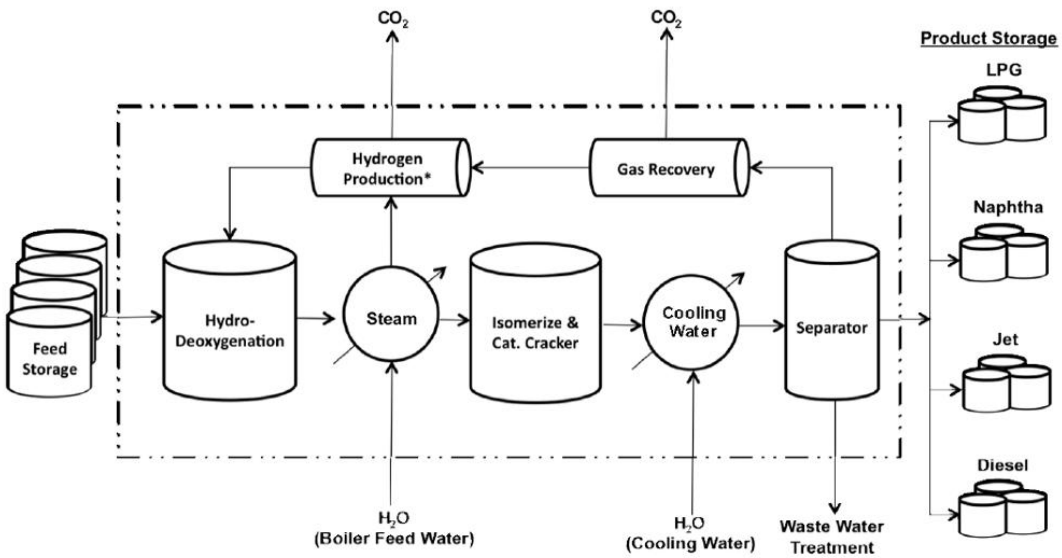


Figure 11. Simplified Hydropressing Renewable Oils System Design (From Pearlson, 2011)

c. *Direct Synthesis Algal*

Algae are currently being used as a source of oil for biofuel pathways as seen above in Figure 8. Algae have many advantages to other biomass crops. These advantages were outlined in the National Algal Biofuels Technology Roadmap released by DOE in 2010, are as follows:

- Algal productivity can offer high biomass yields per acre of cultivation.
- Algae cultivation strategies can minimize or avoid competition with arable land and nutrients used for conventional agriculture.
- Algae can utilize waste water, produced water, and saline water, thereby reducing competition for limited freshwater supplies.
- Algae can recycle carbon from CO_2-rich flue emissions from stationary sources, including power plants and other industrial emitters.
- Algal biomass is compatible with the integrated bio-refinery vision of producing a variety of fuels and valuable co-products. (DOE, 2010)

Bioengineering of algae is leading to direct synthesis of biofuel. Algae are being genetically modified so they will grow or produce biofuel directly. This may

increase the yield of fuel from current estimated levels of 9.1 gallons per cultivated acre of algae pools per day to 41.1 gallons per cultivated acre per day (Griffith, 2011).

Figure 12 shows a summary of the multiple paths from biomass to biofuel. "Near-term conversion technologies as those technologies with planned commercial facilities within the next 5 years, and mid-term conversion technologies which currently have demonstration projects without any commercial facilities planned within the next 5 years" (Griffith, 2011).

Chapter IV analyses the cost of biofuels. The projected supply is from near-term technologies.

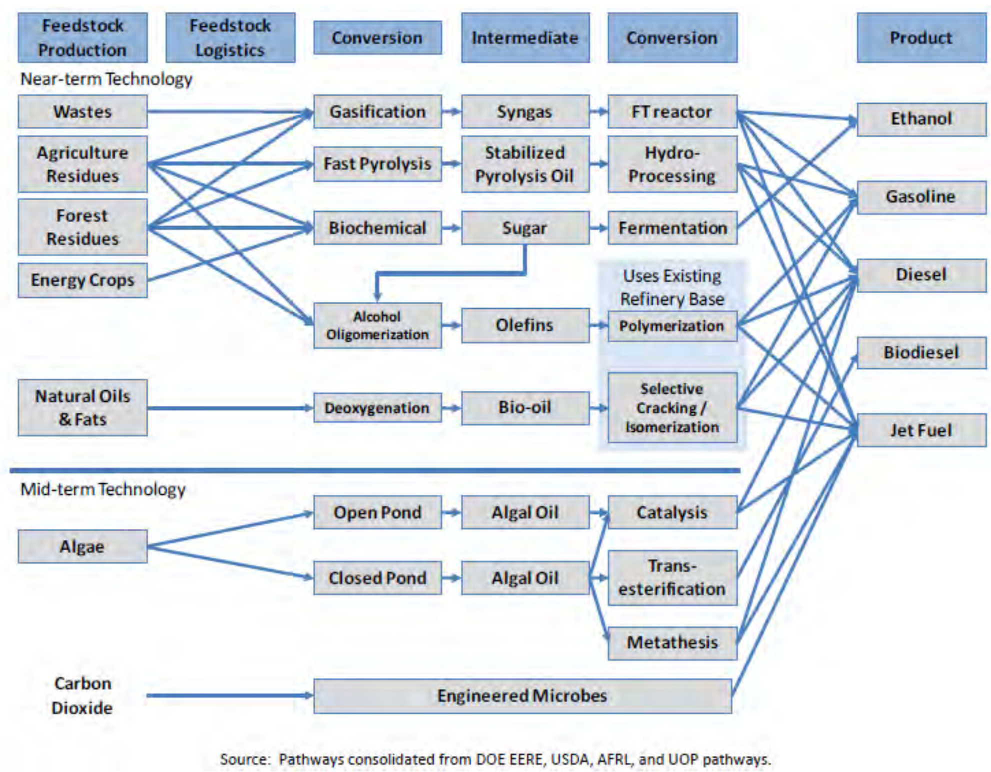


Figure 12. Alternative Fuel Production Pathways (From Griffith, 2011)

4. Fueling the Green Fleet

This thesis examines the cost of biofuel to the end user, the DON. This cost is examined for the Great Green Fleet in 2016 and for 2020 to meet the 50 percent

alternative fuel target for shore and sea installations. Beyond 2020, the cost to the Navy will depend on the development of the industry. The questions which must be answered:

- At what level of production will the cost of biofuel be equivalent to the cost of JP-5?
- What premium over the cost of JP-5 will the DON pay to operate at 50 percent biofuel for Naval Aviation?

Figure 13 shows the Navy's biofuel requirement to reach the 50 percent alternative target by 2020. Nuclear power already accounts for 28 percent of total energy. Increased efficiencies are expected to decrease consumption. This leaves a gap of 22 percent for biofuels. Because of the requirement for liquid fuel, Naval Aviation will account for most of this biofuel consumption.

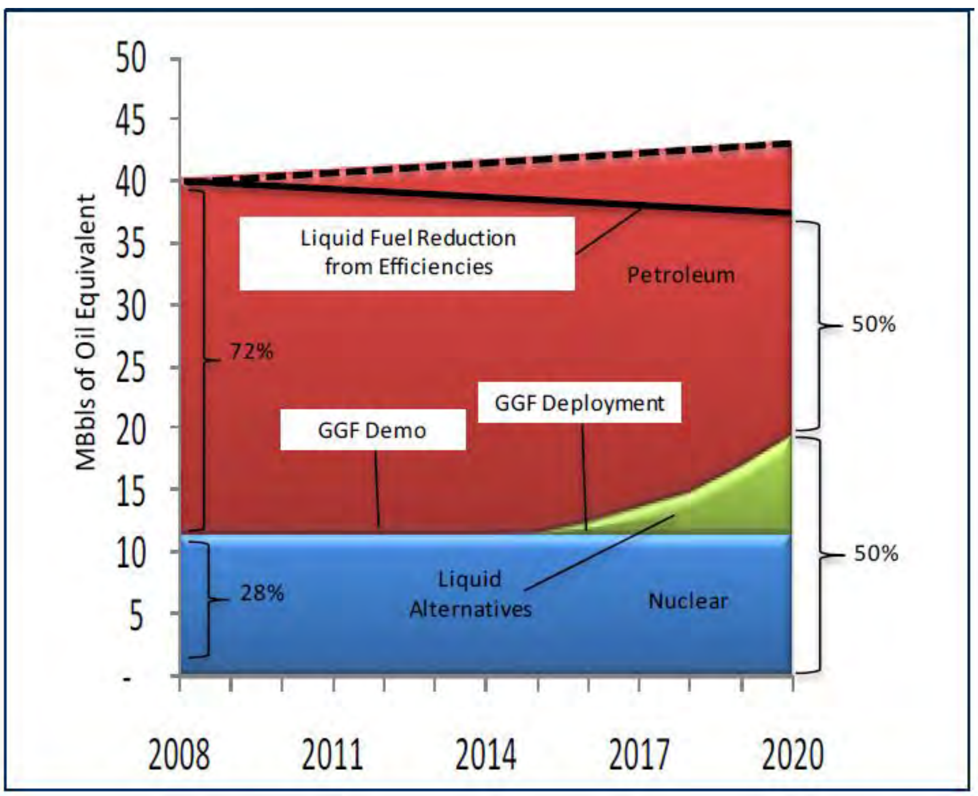


Figure 13. U.S. Navy's Projection of Alternative Tactical Fuel Requirement Afloat to Meet 50 percent goal (From Cullom, 2011)

5. A Cost Estimate of Biofuel

Chapter IV reviews the anticipated supply and demand of biofuel and predicts a cost estimation is made for:

- Great Green Fleet in 2016
- 50 percent alternative fuel goal in 2020
- Further look to 2028.

IV. DATA AND ANALYSIS

A. ESTIMATING THE COST OF BIOFUEL

This chapter examines the premium on current and projected JP-5 costs which the DON will pay to meet the SECNAV goals.

As discussed in Harrison's thesis, it is difficult for a new product or technology to move from research and development to full production. Harrison states that "Consumers' attitudes toward adoption of energy technology may be strongly influenced by political policies, mandates, and regulations geared to the public good rather than to the materialization and desire for the product itself" (Harrison, 2008, p. 50). For the DON, the motivation is increased national security through improved energy security. As a consumer of energy, the Navy may pay a premium for this improvement.

As discussed in Chapter III, there are multiple pathways for developing the end product. Whereas the DON and the DoD support the development of this growing industry for improved national and energy security, cost must play a role in the decision process. In this chapter, all biofuels will be considered the same product, regardless of the method of production. The DoD's position on feedstock and production method is neutral. When a fuel meets specifications, the DoD will pursue the most cost effective alternative (Griffith, 2011).

1. Biofuel Test to Production

In order to predict the future cost for biofuel for this research, historical cost data were examined. Some known costs, like the price paid for fuel used in test and evaluations flights, have been considered. Table 3 shows the volumes and cost per gallon of fuel used for test flights.

Product	Quantity	Cost per Gallon	Total	Feedstock	Service
HRJ5	40,000	$ 66.60	$ 2,664,000	Camelina	Navy
HRJ5	1,500	$ 149.00	$ 223,500	Algal Oil	Navy
HRJ8	100,000	$ 66.80	$ 6,680,000	Camelina	AF
HRJ8	100,000	$ 64.00	$ 6,400,000	Tallow	AF
HRJ8	34,950	$ 38.60	$ 1,349,070	Camelina	Army
HRJ5	150,000	$ 34.45	$ 5,167,500	Camelina	Navy
HRJ8	100,000	$ 34.90	$ 3,490,000	Camelina	AF
HRJ8	100,000	$ 32.40	$ 3,240,000	Tallow	AF
TOTALS	**626,450**		**$ 29,214,070**		
HRJ	**626,450**		**29,214,070**	**$ 46.63**	Avg $/gal

Table 3. HRJ Biofuel Quantities and Cost Purchased in 2009 and 2010 and Used for Test and Evaluation Flights by USN and USAF (After Binder, 2011)

Because these test grade fuels were purchased in low quantities and made to high specification, these prices are not considered an accurate prediction for future costs

2. Economic Factors

A Defense Logistics Agency (DLA) report provides a prediction of the future price per gallon of alternative fuels from 2012 through 2028 (Griffith, 2011). This report is a supplemental to a DoD report on alternative and renewable fuels prepared by the Assistant Secretary of Defense for Operational Energy Plans and Programs and DLA, in conjunction with the military services.

This thesis relies on data from both of these reports in the following sections. The former is referred to as the Griffith report, the latter as the NDAA report. The following sections examine the projected supply and demand of biofuel in order to estimate cost.

a. Biofuel Supply

Biofuel price is predicted based on the stated demand from DoD and projected supplies. Figure 14, from the Griffith report, shows projected supply and demand for biofuel. Demand by commercial aviation and DoD agencies is shown in the

shaded areas. Projected quantities are shown by method of production as millions of gallons per year. The figure depicts projected quantities outpacing current stated demand.

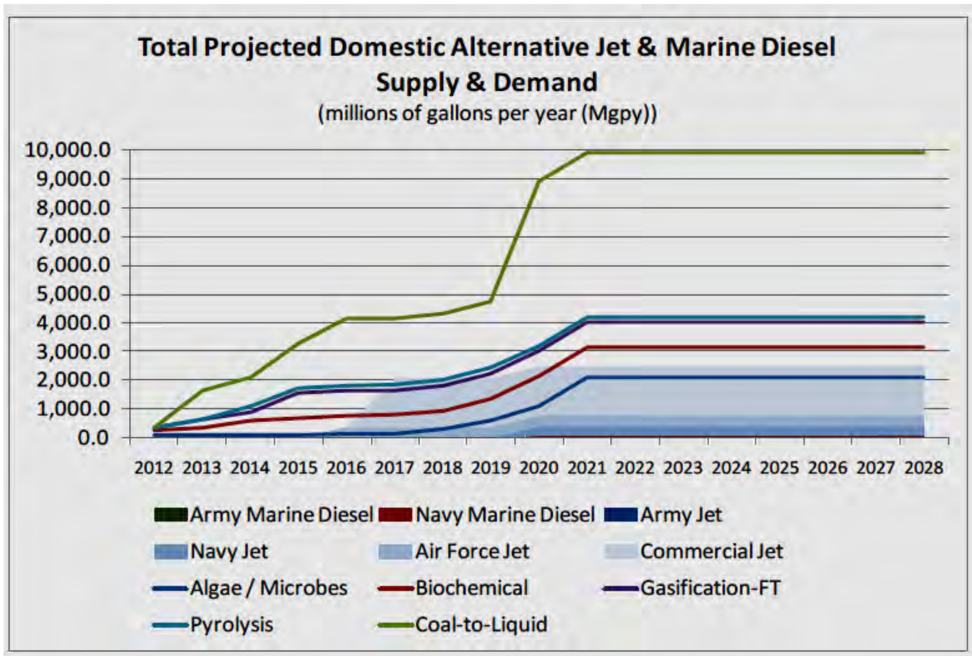


Figure 14. Total Projected Combined DoD and Commercial Demand for Alternative Jet Fuel, DoD Demand for Alternative Marine Diesel, and Total Combined Supply of Alternative Jet & Marine Diesel Fuel from 2012–2028 (From Griffith, 2011)

Table 3 lists the projected quantities of biofuel produced per year. These data are from the Griffith report, sorted by method of production, total volume per year and percent of total volume increase per year. Projected volumes were determined through industry research of planned biofuel refineries. The 370 percent increase in total production from 2012 to 2013 results from the opening of more refineries. Coal to liquid provides for the majority of this increase.

Projected Biofuel Production (Mgal/yr)							
FY	Biochemical	Algae/ Microbes	Pyrolysis	Gasification FT	Coal to Liquid	Total Mgal/yr	% Annual Increase
2012	175.08	101.00	0.06	75.65	0.00	351.79	
2013	233.08	101.01	1.47	305.75	1013.20	1654.51	370%
2014	480.08	102.65	187.61	305.75	1013.20	2089.29	26%
2015	562.08	110.00	193.00	867.80	1545.16	3278.04	57%
2016	632.08	125.00	193.00	867.80	2312.16	4130.04	26%
2017	632.08	155.00	193.00	867.80	2312.16	4160.04	1%
2018	632.08	305.00	193.00	867.80	2312.16	4310.04	4%
2019	762.08	605.00	193.00	867.80	2312.16	4740.04	10%
2020	1033.12	1105.00	193.00	867.80	5700.98	8899.90	88%
2021	1033.12	2105.00	193.00	867.80	5700.98	9899.90	11%
2022	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%
2023	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%
2024	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%
2025	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%
2026	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%
2027	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%
2028	1033.12	2105.00	193.00	867.80	5700.98	9899.90	0%

Table 4. Projected Total Biofuel Production by Year and Method, 2012–2028 (Mgal/yr) (After Griffith, 2011)

Figure 15 depicts the volumes from Table 4 as a percentage of annual production. This figure shows the contribution of each production method to the total annual volume. From 2013 through 2028, Coal to Liquid is projected to be highest volume of any single production method in the U.S. Coal to liquid is produced using the Fischer-Tropsch method, as discussed earlier.

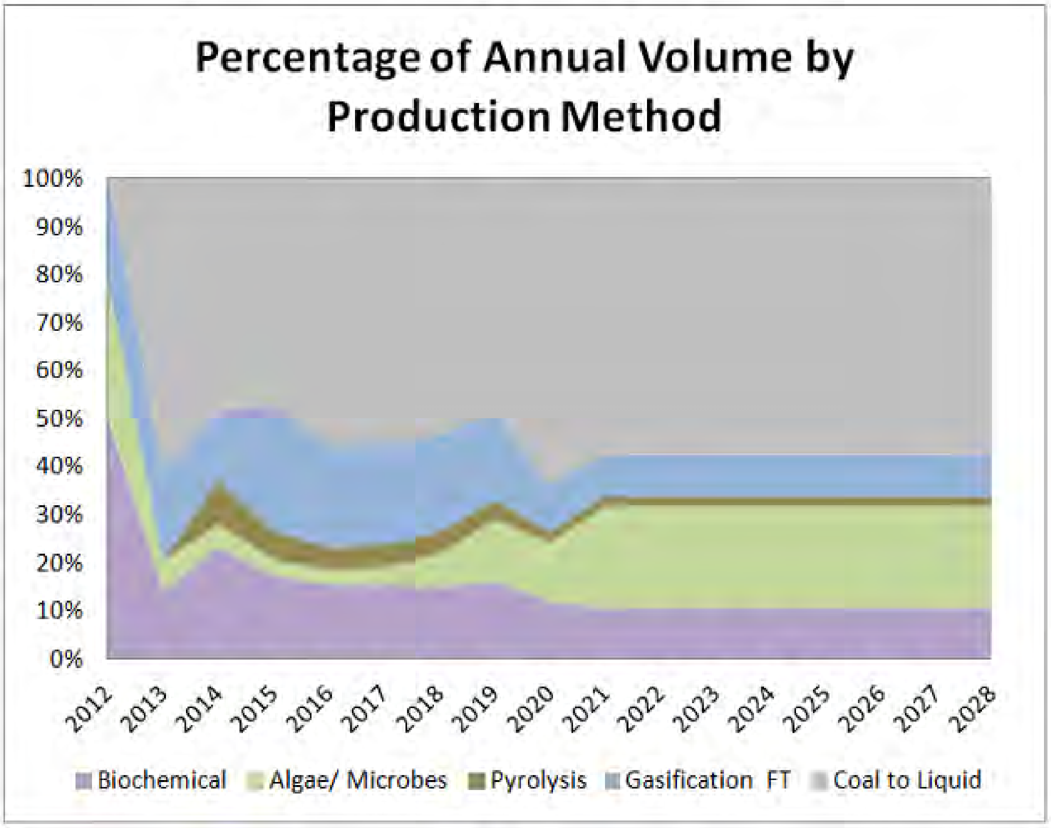


Figure 15. Percentage Of Each Listed Production Method's Contribution to Total Annual Volume of Biofuel in The United States from 2012 to 2028. Data Taken from Griffith, 2011.

The NDAA report reaches the opposite conclusion when looking at the supply and demand of biofuel. This conclusion is reached primarily due to the report disregarding coal to liquid fuel, as the report states:

> DoD faces two major challenges in meeting the Services' goals for renewable fuel use: 1. *Ensuring a sufficient supply of drop-in renewable fuel, particularly jet fuel*. The aggregate supply of drop-in renewable (jet and diesel) fuel may not meet both DoD and commercial demand. Given the Services' goals and projected supply, DoD would have to capture more than 40 percent of the renewable and cellulosic diesel and jet markets in 2020. The Services' 2020 goals for renewable jet fuel alone far exceed even the high-end projected domestic supply (Figure 15).
>
> 2. *Providing drop-in renewable fuel at an acceptable cost*. Drop-in renewable fuels are expected to cost more than their petroleum counterparts: the estimated price premium will be between \$1.43 and \$5.24 per gallon in 2015. Given the Services' goals, mid-range estimates

suggest that DoD's drop-in renewable fuel use would represent an additional annual fuel cost of $865 million by 2015 and $2.2 billion by 2020, which represents a 10– 15 percent increase over just conventional petroleum fuels. (p. v)

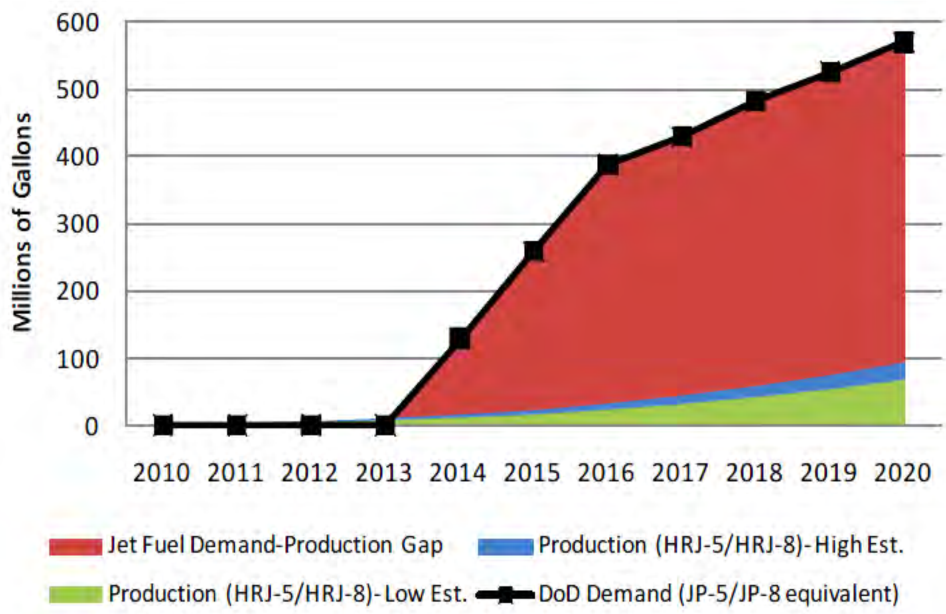


Figure 16. Comparison of DoD Demand for Renewable Jet Fuels and the Projected Supply of these Drop-in Fuels, 2010–20 (From DoD and DLA, 2011)

b. Biofuel Demand

Figure 17 shows DON biofuel quantities of 8000 barrels for 2012, 80,000 barrels for 2016 to meet biofuel requirements for the Great Green Fleet and 8,000,000 barrels for 2020. It shows the requirements for JP-5 alongside F-76, the petroleum ship fuel. Although this thesis concentrates on JP-5, the full DON demand through 2020 is depicted here.

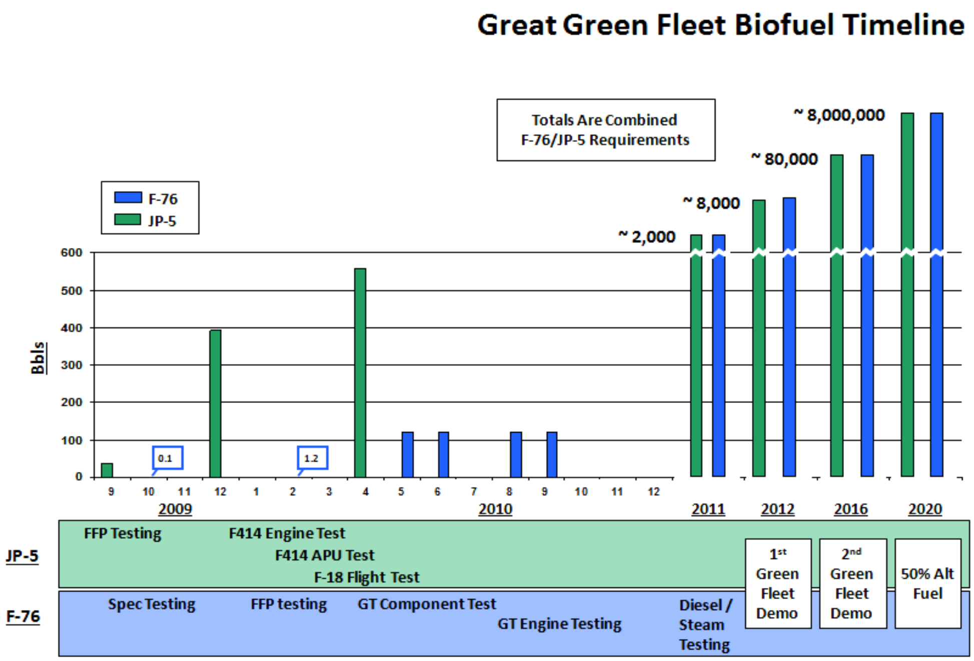


Figure 17. U.S. Navy Biofuel Requirements 2012 to 2020 (From NAVSUP-Energy, 2011)

The NDAA report places the total projected biofuel demand much higher than the DON numbers in Figure 17. Table 5 shows the projected totals by service. Demand for jet fuels makes up "more than 76 percent of the total demand for drop-in renewable fuels by 2020" (DoD and DLA, 2011). Based on these values, total DoD demand for drop-in jet fuels in 2020 would be approximately 567 Mgal.

Projected demand	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Army	—	—	—	—	—	—	—	—	16.05	19.26	22.47
Air Force	0.40	0.40	0.40	0.40	129.43	258.47	387.50	387.50	387.50	387.50	387.50
Navy	0.19	0.32	0.45	0.45	0.56	1.12	1.68	84.00	168.00	252.00	336.00
Total DoD	0.59	0.72	0.85	0.85	129.99	259.59	389.18	471.50	571.55	658.76	745.97

Table 5. DoD Total Tactical Renewable Fuel Consumption by Year (Mgal) (From DoD and DLA, 2011)

In addition to the DoD demand for jet biofuel is the demand from commercial airlines. The International Air Transport Association (IATA) has committed to a carbon neutral growth policy by 2020. This is expected to require a 10 percent

biofuel requirement. When applied to U.S. airliners, this is an additional 1.7 billion gallons a year above the DoD projected demand (Griffith, 2011).

Adding the DoD jet biofuel demands to commercial aviation gives approximately 2.3 billion gallons a year. This figure is still well below the projected supply as seen in Table 4.

c. Supply and Demand Assumptions

There are some explanations for the discrepancies between these reports. The Griffith report was prepared after the NDAA report, and as stated is a supplemental. The NDAA report did not take the coal to liquid projected supply into consideration when written (Griffith, 2011).

Coal to liquid is prepared using the FT process. Traditional FT produces high GHG emissions, in violation of Section 526 as seen in Figure 10. Future FT refineries are expected to be built with carbon capture capabilities. This would lower the GHG emissions, and make them compliant with the Energy Independence and Security Act of 2007, Section 526. Table 4 shows a supply of 8899.9 Mgal/yr in 2020. Figure 14 put the DoD demand for drop-in replaceable jet fuel near 550 Mgal/yr.

This thesis makes two assumptions on the supply of biofuel:

- Refineries discussed in the Griffith report will be completed and produced at projected volumes of biofuel.
- These refineries will produce biofuel below the traditional band of GHG emissions, as seen in Figure 9, in compliance with Section 526 of the 2007 EPA law.

Therefore, the supply of biofuel should be sufficient to meet demand from the DoD and commercial aviation.

3. Projected Cost of Biofuel

In preparation of his report, Griffith researched the biofuel industry’s planned refineries and projected outputs, listed in the Appendix. Biofuel price predictions were made by taking an average price per gallon of projected fuel supplies given three possible scenarios of refinery technology:

- Pessimistic, with current technology
- Optimistic, with current technology
- Likely, with technology improvements (Griffith, 2011, p. 7)

Prices for each scenario are enough to recover total start up and operating costs, which include:

- Capital costs for constructing new refineries
- Cost of feedstock as raw material
- Operating and overhead costs

As stated earlier, this thesis assumes that the refineries will produce sufficient supply to meet expected demand.

Table 6 lists the predicted alternative fuel price per gallon under each scenario on the left of the table. The center column has the projected price per gallon of a petroleum based “traditional fuel.” This price is based on data found in the Department of Energy 2009 Annual Energy Outlook.

An alternative fuel premium was then derived by subtracting the traditional fuel cost from the alternative fuel cost in each category. Therefore, the premium is simply how much more a gallon of biofuel may cost than a gallon of JP-5. The data are listed for the years 2012 to 2028 (Griffith, 2011).

FY	Cost Estimate for Biofuel $/gal			- (Fuel) = $/gal	Premium paid for Biofuel $/gal		
Scenario	Pessimistic	Optimistic	Likely	Traditional Fuel	Pessimistic	Optimistic	Likely
2012	$19.00	$10.24	$11.43	$2.73	$16.27	$7.51	$8.70
2013	$7.05	$3.83	$4.33	$2.84	$4.21	$0.99	$1.49
2014	$7.26	$4.17	$4.17	$2.95	$4.31	$1.22	$1.22
2015	$7.37	$4.08	$4.31	$3.05	$4.32	$1.03	$1.26
2016	$6.44	$3.59	$3.80	$3.24	$3.20	$0.35	$0.56
2017	$6.67	$3.70	$3.97	$3.41	$3.26	$0.29	$0.56
2018	$7.76	$4.19	$4.81	$3.58	$4.18	$0.61	$1.23
2019	$9.76	$5.16	$6.24	$3.75	$6.01	$1.41	$2.49
2020	$11.23	$5.71	$7.46	$3.90	$7.33	$1.81	$3.56
2021	$11.23	$5.71	$7.46	$4.00	$7.23	$1.71	$3.46
2022	$11.23	$5.71	$7.46	$4.14	$7.09	$1.57	$3.32
2023	$11.23	$5.71	$7.46	$4.27	$6.96	$1.44	$3.19
2024	$11.23	$5.71	$7.46	$4.42	$6.81	$1.29	$3.04
2025	$11.23	$5.71	$7.46	$4.56	$6.67	$1.15	$2.90
2026	$11.23	$5.71	$7.46	$4.68	$6.55	$1.03	$2.78
2027	$11.23	$5.71	$7.46	$4.82	$6.41	$0.89	$2.64
2028	$11.23	$5.71	$7.46	$4.94	$6.29	$0.77	$2.52

Table 6. Forecasted Average Premium per Gallon of "neat" Biofuel Fuel based on Planned Suppliers of Middle Distillate Alternative Fuels. Data from Griffith (2011).

The reduction in price from 2012 to 2013 appears to be the only discrepancy with these data. However, the data on predicted production quantity for 2013 in Table 4 offer an explanation. The quantity data show a 370 percent increase in production from 2012 to 2013. This increase in supply drops the price under each scenario approximately 63 percent. With further projected growth in production over the next three years, another drop in price is seen in 2016.

Discounts from increases in quantity and efficiency improvements along with the effect of inflation will be examined later in this chapter.

B. BIOFUEL COST COMPARISON TO JP-5

This section examines the premium paid and in some cases the discounts gained for use of drop-in replaceable biofuels blended at a 50/50 ratio. Using the projected cost per gallon of biofuel outlined above, cost data were studied in relation to the projected cost of JP-5.

In the DON budget planning phase, guidance is given on the annual inflation rates. The latest guidance lists annual rates for fuel inflation as (DON FY13 Budget Guidance, 2011):

- FY13 3.2 percent
- FY14 0.6 percent
- FY15 0.6 percent
- FY16 1.2 percent
- FY17 2.2 percent

For the years 2018 to 2028, this thesis uses the FY17 rate of 2.2 percent. These inflation rates will remain the same for the remainder of the thesis.

Table 7 shows the projected cost of biofuel in comparison to JP-5. The cost of JP-5 is inflated from the FY12 Standard Cost of $3.97/gal using the above DON FY13 Budget Guidance. The premium shows the additional cost paid per gallon of biofuel. Discounts occur when the projected cost of biofuel is less than the projected cost of JP-5.

FY	Cost Estimate for Biofuel $/gal			- (JP-5) = $/gal	Premium paid for Biofuel $/gal		
Scenario	Pessimistic	Optimistic	Likely	JP-5 Cost	Pessimistic	Optimistic	Likely
2012	$19.00	$10.24	$11.43	$3.97	$15.03	$6.27	$7.46
2013	$7.05	$3.83	$4.33	$4.10	$2.95	($0.27)	$0.23
2014	$7.26	$4.17	$4.17	$4.12	$3.14	$0.05	$0.05
2015	$7.37	$4.08	$4.31	$4.15	$3.22	($0.07)	$0.16
2016	$6.44	$3.59	$3.80	$4.20	$2.24	($0.61)	($0.40)
2017	$6.67	$3.70	$3.97	$4.29	$2.38	($0.59)	($0.32)
2018	$7.76	$4.19	$4.81	$4.38	$3.38	($0.19)	$0.43
2019	$9.76	$5.16	$6.24	$4.48	$5.28	$0.68	$1.76
2020	$11.23	$5.71	$7.46	$4.58	$6.65	$1.13	$2.88
2021	$11.23	$5.71	$7.46	$4.68	$6.55	$1.03	$2.78
2022	$11.23	$5.71	$7.46	$4.78	$6.45	$0.93	$2.68
2023	$11.23	$5.71	$7.46	$4.89	$6.34	$0.82	$2.57
2024	$11.23	$5.71	$7.46	$4.99	$6.24	$0.72	$2.47
2025	$11.23	$5.71	$7.46	$5.10	$6.13	$0.61	$2.36
2026	$11.23	$5.71	$7.46	$5.22	$6.01	$0.49	$2.24
2027	$11.23	$5.71	$7.46	$5.33	$5.90	$0.38	$2.13
2028	$11.23	$5.71	$7.46	$5.45	$5.78	$0.26	$2.01

Table 7. Forecasted Average Premium or (Discount) per Gallon of Biofuel when Compared to the Projected Cost of JP-5. Biofuel Data from Griffith (2011).

1. Premium for Blended Gallon

Table 7 shows the premium or discount as the difference paid between one gallon of biofuel and one gallon of JP-5. The DON will be using biofuel as a drop-in replacement fuel, blended at a 50/50 ratio (Cullom, 2011). As a result, the cost for each gallon of fuel will be the average of the two prices. Every gallon of 50/50 blended fuel replaces one gallon of JP-5. The premium for a blended gallon of fuel thus becomes the average price less the one gallon of JP-5. Stated as:

Premium for a 50/50 gallon = ($Avg. cost of Biofuel and JP-5/gal) - $JP-5/gal

Table 8 shows the premium for a blended gallon of fuel mixed at a 50/50 ratio with JP-5. This is the additional cost paid per gallon over the projected cost of JP-5. For

periods of a projected discount, this would be the amount saved by not buying the gallon of JP-5. Compared to the premium in Table 7, blended premium values are halved.

FY	Cost Estimate for Biofuel $/gal			JP-5 $/gal	Premium/(Discount) for 50/50 Biofuel/JP-5 gallon - $/gal		
Scenario	Pessimistic	Optimistic	Likely	JP-5 Cost	Pessimistic	Optimistic	Likely
2012	$19.00	$10.24	$11.43	$3.97	$7.52	$3.14	$3.73
2013	$7.05	$3.83	$4.33	$4.10	$1.48	($0.13)	$0.12
2014	$7.26	$4.17	$4.17	$4.12	$1.57	$0.02	$0.02
2015	$7.37	$4.08	$4.31	$4.15	$1.61	($0.03)	$0.08
2016	$6.44	$3.59	$3.80	$4.20	$1.12	($0.30)	($0.20)
2017	$6.67	$3.70	$3.97	$4.29	$1.19	($0.29)	($0.16)
2018	$7.76	$4.19	$4.81	$4.38	$1.69	($0.10)	$0.21
2019	$9.76	$5.16	$6.24	$4.48	$2.64	$0.34	$0.88
2020	$11.23	$5.71	$7.46	$4.58	$3.33	$0.57	$1.44
2021	$11.23	$5.71	$7.46	$4.68	$3.28	$0.52	$1.39
2022	$11.23	$5.71	$7.46	$4.78	$3.22	$0.46	$1.34
2023	$11.23	$5.71	$7.46	$4.89	$3.17	$0.41	$1.29
2024	$11.23	$5.71	$7.46	$4.99	$3.12	$0.36	$1.23
2025	$11.23	$5.71	$7.46	$5.10	$3.06	$0.30	$1.18
2026	$11.23	$5.71	$7.46	$5.22	$3.01	$0.25	$1.12
2027	$11.23	$5.71	$7.46	$5.33	$2.95	$0.19	$1.06
2028	$11.23	$5.71	$7.46	$5.45	$2.89	$0.13	$1.01

Table 8. Projected Premium or (Discount) for each Gallon of Blended 50/50 Fuel. Biofuel Data from Griffith (2011)

Using the values calculated in Table 8, the following section analyzes the cost to CVW operations for the Great Green Fleet and beyond.

2. The Premium for CVW Operations

The DON operates Carrier Strike Groups continuously around the world. Consumption of JP-5 for flight operations can be considered at a constant rate.

As shown in Chapter III, the Nimitz Class CVN has capacity for 3.3 million gallons of aviation fuel, currently JP-5. At the FY12 standard price of $3.97/gal, the cost is $13.1M to fill these tanks with JP-5, as seen in Chapter III, Table 1, on page 19.

At the rate of flight operations shown in Table 2, an equivalent amount of fuel to empty the CVN's aviation fuel tanks is burned every 28 days.

Using data from Table 8, the premium and/or discount for blending JP-5 with biofuel will be examined for three future years.

- 2016 - the deployment of the Great Green Fleet
- 2020 - the first year of 50 percent continuous alternative fuel use
- 2028 - the final year of the projected data

Table 9 condenses Table 8 for the three years of interest.

FY	Cost Estimate for Biofuel $/gal			JP-5 $/gal	Premium/(Discount) for 50/50 Biofuel/JP-5 gallon - $/gal		
Scenario	Pessimistic	Optimistic	Likely	JP-5 Cost	Pessimistic	Optimistic	Likely
2016	$6.44	$3.59	$3.80	$4.20	$1.12	($0.30)	($0.20)
2020	$11.23	$5.71	$7.46	$4.58	$3.33	$0.57	$1.44
2028	$11.23	$5.71	$7.46	$5.45	$2.89	$0.13	$1.01

Table 9. Projected Premium or (Discount) for each Gallon of Blended 50/50 fuel for Focus Years

Table 10 summarizes the DON projected costs for a full load of JP-5 and the 50/50 biofuel blended fuel for a CVN during the focus years in millions of dollars. A premium is seen in most of the scenarios for the blended fuel. Discounts are seen in the Optimistic and Likely scenarios for 2016.

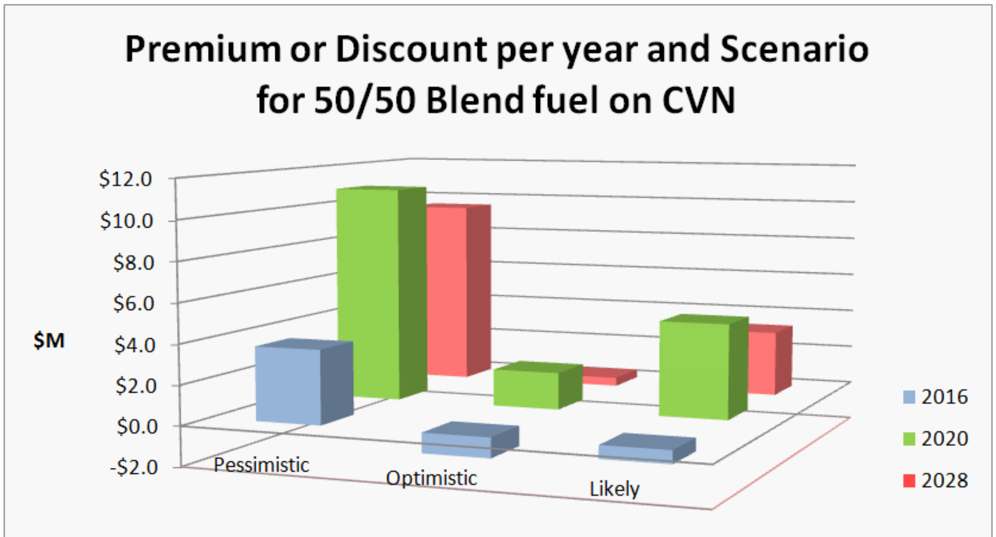
When looking at 2016, it may cost $13.8M to fill the CVN to full capacity with JP-5, $17.5M for the blend under Pessimistic, $12.8M under Optimistic, and $13.1M under Likely.

	Cost for JP-5 $M	Premium for Blend 50/50 Fuel $M		
		Pessimistic	Optimistic	Likely
2016	13.8	3.7	(1.0)	(0.7)
2020	15.1	11.0	1.9	4.8
2028	18.0	9.5	0.4	3.3

Table 10. Projected Costs for a Full Fuel Capacity of 3.3 Mgal on a CVN for the Focus Years. JP-5 on the Left and a 50/50 JP-5/Biofuel Blend on the Right for Each Scenario.

Whereas discounts on biofuels are not predicted by most studies, using the assumptions in supply and demand and only inflating the cost of JP-5, they do occur with these data. However, it is important to note that these biofuels are drop-in replaceable. As such, they are chemically the same product as petroleum jet fuel. Therefore, the expectation is that they will never be cheaper than the market price of petroleum based fuels.

Figure 18 depicts the premium and discount for each scenario in the three focus years.



	Pessimistic	Optimistic	Likely
2016	3.7	(1.0)	(0.7)
2020	11.0	1.9	4.8
2028	9.5	0.4	3.3

Figure 18. Projected Premium and (Discount) on 50/50 Blended Fuel in Focus Years for Single Fuel Load of 3.3Mgal on CVN

a. Great Green Fleet

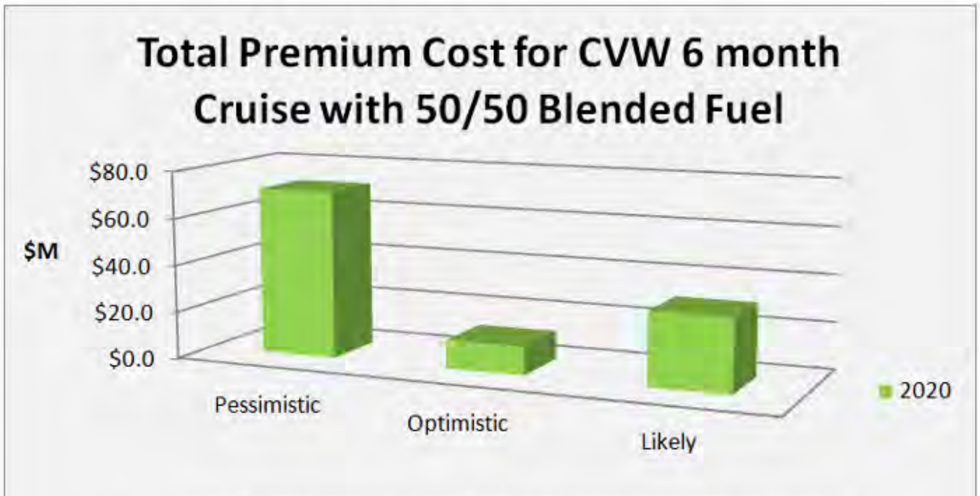
When the Great Green Fleet sails in 2016, it will have one full capacity of 50/50 blended fuel. These figures show that the most this may cost is an additional \$3.7M over the projected cost of JP-5. Since a discount is shown in the optimistic and likely scenarios, the cost is predicted to be the equal to the cost of 100 percent JP-5.

b. 50 Percent Biofuel in 2020

For 2020, the initial year of 50 percent alternative fuel at sea and shore, the costs will be projected for one CVW during one full six-month cruise. Given the rate of fuel consumption shown in Table 2, the following calculations estimate the cost of CVW operations in 2020. This thesis assumes that the CVN leaves port with 3.3 Mgal of blended fuel. The fuel is refilled at 50 percent capacity, or 1.65 Mgal. This is approximately every 14 days, or eleven times in a six month cruise, equivalent to filling the fuel tanks 6.5 times.

- *Pessimistic: Premium paid for 50/50 blend = 6.5 x $11M*
- *Optimistic: Premium paid for 50/50 blend = 6.5 x $1.9M*
- *Likely: Premium paid for 50/50 blend = 6.5 x $4.8M*

Figure 19 depicts the premium for a six month CVW cruise. Premium figures are in addition to the cost of JP-5. Calculations are not exact due to rounding values.



	Pessimistic	Optimistic	Likely
2020 $M	$71.3	$12.1	$30.9

Figure 19. Projected Total Premium for 50/50 Blended Fuel During a 6 month CVW Deployment

C. FORCES ON THE PRICE OF BIOFUEL

The future cost of biofuel is unknown and will vary. There are multiple market and production factors which will affect the costs and the final price of the product. Some of these include the cost of raw materials, transportation costs, and capital investment costs.

Three forces examined here for their effects on the final price are:

- Quantity discounts
- Efficiency improvements
- Inflation

These three forces are examined for their long range effects on the price of biofuels and how they affect the premium paid by the DON. As stated in the Griffith report:

> Today, estimated costs for sustainable alternative jet and marine diesel fuels range from 2–5 times the cost of conventional jet and marine diesel fuels and in some cases (as in algae-derived fuels) they range even higher. As new fuel production technologies and larger plants come online, they will bring several benefits including economies of scale, capital cost reduction, operating and maintenance efficiencies and greater experience resulting in further reduction of costs. The International Energy Agency has projected costs for facilities employing current conversion technologies to be reduced by about 40 percent between now and 2030. (Griffith, 2011)

1. Quantity Discounts

Because the DoD is a large customer for fuels, DLA is able to negotiate discounts for large purchases. As Griffith states in his report, "DoD 4140–25-M details DLA Energy to develop worldwide purchase programs structured to the needs of the Military Services in order to consolidate DoD requirements by region to obtain lowest possible unit cost of product" (Griffith, 2011). Since DoD is currently the primary customer for biofuels, quantity discounts may be negotiated in the purchase contracts. These discounts may be aided by continued production improvements as discussed following.

2. Efficiency Improvements

Economies of scale may be a large influence on bringing the cost of biofuel closer to petroleum fuels. Currently, there are very few biofuel refineries in the U.S. As seen in Table 4, projected biofuel quantity for 2012 is 351.79 million gallons. In 2013 this amount increases by 370 percent to 1,654.5 million gallons. The price per gallon is projected to fall over 60 percent in this year alone, with the data used in this thesis. However, much of this is dependent on the manufacturers meeting their estimated quantity goals.

In future years, as refineries improve their operations, their output may increase. This will bring the cost per gallon down, and prices may follow.

The following figures show the cumulative effects of quantity discounts and efficiencies. Both factors should help to bring the price per gallon of biofuel closer to petroleum. If this industry is to survive, the price of the commodity must approach parity with petroleum.

3. Inflation

Inflation is projected by the DON for planning and budgeting purposes out to five years. The inflation rate used for JP-5 was listed in section B of this chapter. When considering inflation, both biofuel and JP-5 should be affected at the same rate. Therefore, inflation will have little effect on the premium paid for biofuel.

The following figures show JP-5 inflated at the same rate as in Table 7. The price reduction of biofuel can be seen as a net reduction after all three factors were considered.

4. Sensitivity Analysis

The following figures show at what rate the combined effects of quantity discounts and operational efficiency improvements may help to bring the price of biofuel down. Each figure uses 5 percent and 8 percent annual price reductions as references. The figures show the annual rate of price decrease for each scenario in order to reach a parity price in 2020, the first year of the DON 50 percent alternative fuel objective.

Figure 20 shows the Pessimistic scenario. Using the same data and beginning with the projected cost per gallon of biofuel in 2012, the annual price reduction must be approximately 16.4 percent in order to reach the parity price by 2020. Once the price of biofuel reaches the price of JP-5, it is expected to stay the same.

Figures 21 and 22 show the same for the Optimistic and the Likely scenarios, respectively.

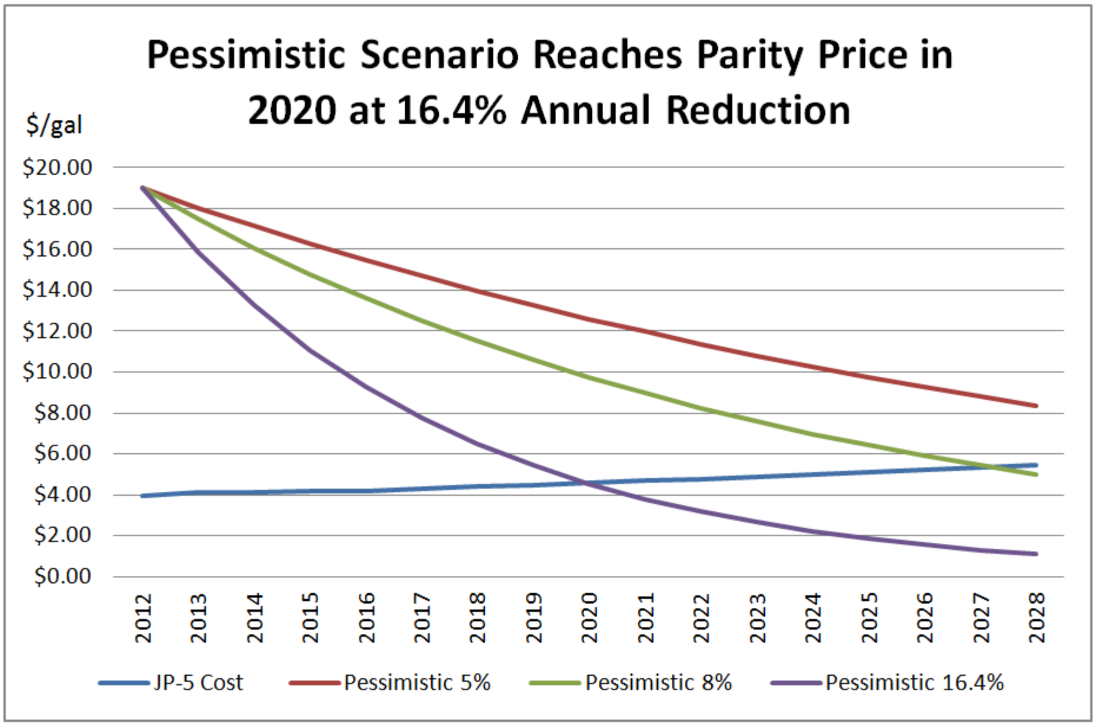


Figure 20. Projected Cost Per Gallon of Biofuel under the Pessimistic Scenario

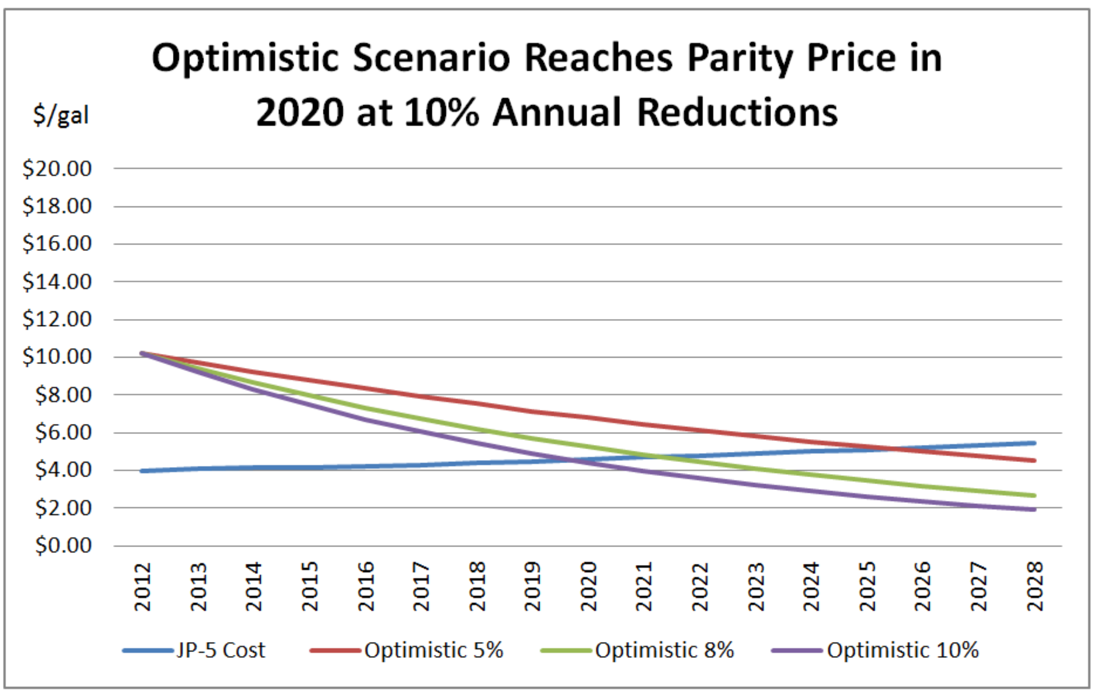


Figure 21. Projected Cost Per Gallon of Biofuel under the Optimistic Scenario

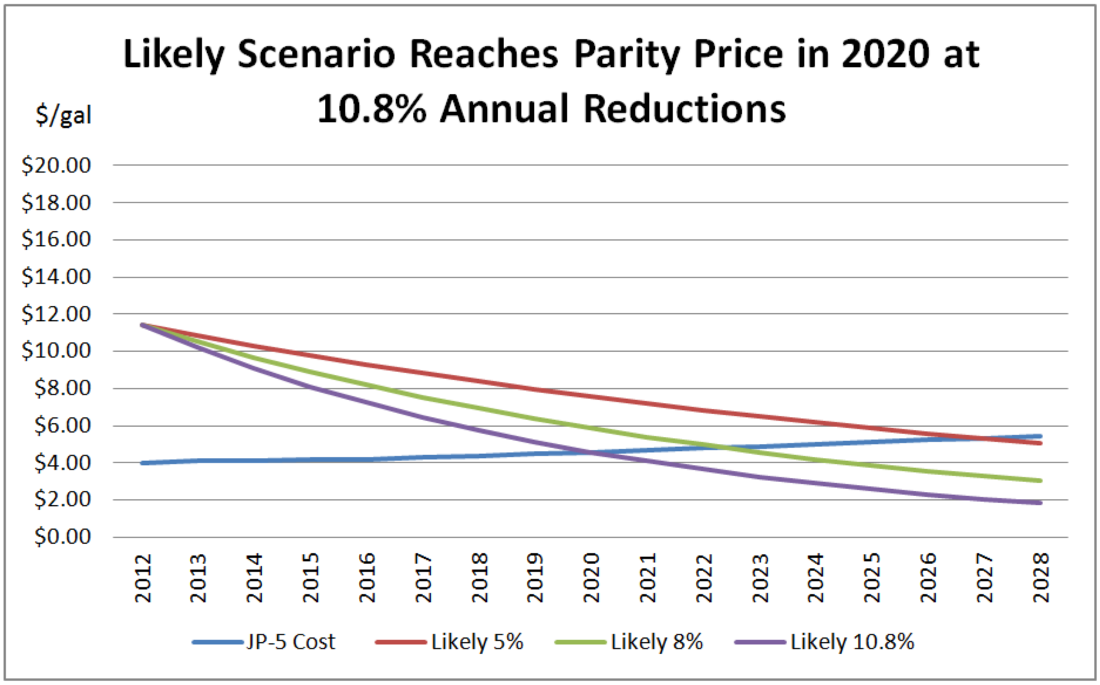


Figure 22. Projected Cost Per Gallon of Biofuel under the Likely Scenario

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSIONS AND FURTHER STUDY

A. CONCLUSIONS

Continued growth of a U.S. based biofuel industry may decrease U.S. dependency of foreign petroleum. This new domestic biofuel industry may increase energy independence and lead to improved national security. The additional cost or premium paid for biofuel by the DON in the near term may be worth the long term goals for the United States.

Although, the future cost of any product is unknown, this thesis provides a cost estimate for biofuel use with the CVW of the Great Green Fleet and into future years. In the near years, the DON will pay more to use biofuel blended fuel. This difference is shown as a premium paid over the cost of JP-5. Based on the projected biofuel cost data, this premium may decrease until there is price parity with JP-5.

Assuming that projected supply of biofuel meets demand, predicted cost data for biofuel were used to find specific premiums for the Great Green Fleet in 2016 and for 2020, the first year of 50 percent alternative fuels use. Under the Pessimistic scenario, the CVW may cost a premium of $3.7M to fill the fuel holds with blended biofuel on the CVN. For the Optimistic and Likely scenarios, there may be no additional cost. When projecting the costs to 2020, the premium was predicted for a single CVW six month deployment. Again, three scenarios were analyzed, Pessimistic, Optimistic and Likely. The resulting premiums for the three scenarios may be $71.3M, $12.1M or $30.9M, respectively.

B. AREAS FOR FURTHER RESEARCH

Areas which were not considered in this thesis, but could affect the price of biofuel are listed. These should be considered for further study.

- Effect of government subsidies to oil and biofuel industries on the price parity of both commodities.
- Effects of growth of new biomass crops on the price of food crops.

- Reaction from oil exporting nations, like OPEC member states, to a new competitor in the fuel market. How high does the price of oil have to be for biofuel to be competitive? How low can the price of oil fall to possibly eliminate the biofuel industry? What is the tipping point?

- Does the use of coal for biofuel make sense? Are there negative externality costs associated with the environmental impact?

- What is the cost of GHG emissions associated with biofuel production?

APPENDIX

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
AltAir Fuels, LLC	Biochemical	75.00	75.00	100.00	100.00	100.00	100.00	100.00	100.00	370.00	370.00	370.00	370.00	370.00	370.00	370.00	370.00	370.00
American Clean Coal Fuels	Coal to Liquid	0.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	987.00	987.00	987.00	987.00	987.00	987.00	987.00	987.00	987.00
Amyris	Biochemical	1.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02	27.02
Ohio River Clean Fuels	Coal to Liquid	0.00	0.00	0.00	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28	268.28
Bell Bio Energy	Gasification _FT	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
Byogy	Biochemical	13.00	45.00	130.00	200.00	270.00	270.00	270.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00
Clean Coal Power Ops	Coal to Liquid	0.00	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20	613.20
DKRW Advanced Fuels	Gasification _FT	0.00	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95	229.95
Dynamic Fuels, LLC	Biochemical	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
Fairbanks CTL Project	Coal to Liquid	0.00	0.00	0.00	263.68	263.68	263.68	263.68	263.68	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25
HR BioPetroleum	Algae/ Microbes	0.00	0.00	1.60	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Diamond Green Diesel	Biochemical	0.00	0.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00	137.00
Flambeau River Biofuels	Pyrolysis	0.00	0.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00
Clearfuels Technology	Gasification _FT	0.00	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Joule Biotechnologies	Algae/ Microbes	0.00	0.01	0.05	5.00	20.00	50.00	200.00	500.00	1000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00
LS9	Biochemical	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10	10.10
Many Stars Project	Coal to Liquid	0.00	0.00	0.00	0.00	767.00	767.00	767.00	767.00	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25	1916.25
Promethean Biofuels	Biochemical	0.00	0.00	0.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
New Page Corp	Pyrolysis	0.00	0.00	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20
Remediation Earth, Inc	Pyrolysis	0.00	0.61	0.61	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Rentech	Gasification _FT	0.00	0.00	0.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00	18.00
Rentech	Gasification _FT	0.15	0.15	0.15	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70	444.70
Sapphire Energy	Algae/ Microbes	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Solazyme	Algae/ Microbes	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Terrabon	Gasification _FT	0.50	0.50	0.50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
UOP	Pyrolysis	0.06	0.06	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00	160.00
Viesel	Biochemical	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
REII	Pyrolysis	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	TOTAL Mgal/yr	351.79	1,654.51	2,083.29	3,278.04	4,130.04	4,160.04	4,310.04	4,740.04	8,899.90	9,899.90	9,899.90	9,899.90	9,899.90	9,899.90	9,899.90	9,899.90	9,899.90
	% CHANGE Quant		370%	26%	57%	26%	1%	4%	10%	88%	11%	0%	0%	0%	0%	0%	0%	0%

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Air Transport Action Group. (2009, May). *Beginer's guide to aviation biofuels.* Retrieved June 13, 2011, from www.enviro.aero/biofuels: http://www.enviro.aero/Beginners-guide-to-Aviation-Biofuels.aspx

Alexander D. S. P. (2010, March 21). *The new dawn of naval energy, the U.S. Navy's updated energy roadmap.* Retrieved June 8, 2011, from www.dawnbreaker.com: http://www.dawnbreaker.com/about/phase3_spr10/energy.php

Andrews, A. (2009). *Department of defense fuel spending, supply, acquisition, and policy.* Washington, D.C.: Congressional Research Service.

Bartis, J. T., & Van Bibber, L. (2011). *Alternative fuels for military applications.* Santa Monica: RAND.

Bhargava, A. (2011, June). *Drop-in replacement biofuels: meeting the challenge*. Cambridge, MA: Massachusetts Institute of Technology.

Biofuels International. (2011, October 31). *Biofuels glossary*. Retrieved October 31, 2011, from Biofuels International Expo & Conference: http://www.biofuelsinternationalexpo.com/bio_glossary.html

Cullom, P. (2011, April 19). Navy Energy Program. Washington, D.C

Daly, J. C. (2011, June 7). *Are biofuels ready to takeoff?* Retrieved June 8, 2011, from http://www.minyanville.com/businessmarkets/articles/ethanol-fuel-biofuels-algae-camelina-camelina/6/7/2011/id/34993?page=full

Danigole, M. S. (2007). *Biofuels an alternate to u.s. air force petromeum fuel dependency.* Maxwell Air Force Base: Center for Strategy and Technology.

Defense Logistics Agency, Energy. (2011, October 21). *DLA Energy*. Retrieved October 20, 2011, from Defense Logistics Agency Energy: ttp://p2web.desc.dla.mil/pls/p2wp/std_price_pkg.std_price_list

Department of Defense and Defense Logistics Agency. (2011). *Opportunities for DoD use of alternative and renewable fuels: FY10 NDAA section 334 Congressional study.* Washington, D.C.: DoD.

Department of Energy. (2009). *Annual energy outlook 2009: With Projections to 2030.* Washington, D.C.: Energy Information Administration.

Department of Energy. (2010, May). *National algal biofuels technology roadmap*. Washington, D.C., USA.

Deputy Assistant Secretary of the Navy, (DASN) Energy Office. (2010). *Department of the Navy's Energy Program for Security and Independence.* Retrieved June 17, 2011, from Greenfleet.dodlive.mil:http://greenfleet.dodlive.mil/files/2010/04/Naval_Energy_Strategic_Roadmap_100710.pdf

Energy Information Administration. (2011, October 20). *U.S. Energy Information Administration*. Retrieved October 18, 2011, from www.eia.gov: http://www.eia.gov/energy_in_brief/foreign_oil_dependence.cfm

Gorin, S. (2010, April 6). Growing America's Energy Future, U.S. Department of Energy, Biomass Program.

Griffith, P. A. (2011). *DoD's Alternative Fuels: A Business Case Assessment (BCa) – Version 1.0.* Richmond: Defense Logistics Agency Operartions Research and Resourse Analysis (DLA DORRA).

Harrison, W. E. (2008, June). *Alternative Fuels: How can Aviation Bridge the 'Valley of Death.'* Cambridge, MA, USA: Massachusetts Institue of Technology.

Hileman, J. I., Ortiz, D. S., Bartis, J. T., Wong, H. M., Donohoo, P. E., Weiss, M. A. (2009). *Near-term feasibility of alternative jet fuels.* Santa Monica: RAND Corportaion.

Johnson, T. (2011, May 6). *Oil Market Volatility.* Retrieved June 10, 2011, from http://www.cfr.org/energy/oil-market-volatility/p15017

Kagan, J. (2010, April 01). *Commercial Jet Biofuel: Sooner Than We Think? Who will win the race between Fischer-Tropsch and hydroprocessed aviation fuels?* Retrieved October 05, 2011, from http://www.greentechmedia.com/articles/read/commercial-jet-fuel-sooner-than-we-think/

Mabus, R. (2009). Remarks by Secretary of the Navy. *Naval Energy Forum*. McLean, VA, 2009.

NAVAIR Public Affaris Office. (2011, September 30). *Fire Scout Completes First Navy Unmanned Flight On Biofuel*. Retrieved October 01, 2011, from http://www.navy.mil/search/display.asp?story_id=63026

NAVAIR Public Affairs Office. (2011, August 30). *First Navy trainer completes biofuel flight*. Retrieved October 01, 2011, from Navy.mil:

http://www.dodlive.mil/index.php/2011/08/first-navy-trainer-completes-biofuel-flight/#more-22410

NETL, National Energy Technology Laboratory. (2008, April). Retrieved October 01, 2011

NSS. (2010, May). *National security strategy*. Washington, DC, USA.

O'Keeffe, N. (2010, February 22). *Aviation biofuels: the bumpy road to scale production.* Retrieved June 6, 2011, from http://www.flightglobal.com/articles/2010/02/22/338613/aviation-biofuels-the-bumpy-road-to-scale-production.html

Pearlson, M. N. (2011, June). *A techno-economic and environmental assessment of hydroprocessed renewable distillate fuels*. Cambridge, MA, USA: Massachusetts Institute of Technology.

Roth, J. P. (2011, September 28). Fiscal Year (FY) 2012 Fuel Price Change. Washington, D.C., U.S.A.: Office of the Under Secretary of Defense, Comptroller.

Weisgerber, M. (2011, March 11). *DoD may seek extra $1.5B in fuel costs.* Retrieved June 6, 2011, from http://www.defensenews.com/story.php?i=5934795

The White House. (2011). *Blueprint for a secure energy future.* Washington, D.C.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Dr. Daniel Nussbaum
   Naval Postgraduate School
   Monterey, California

4. John Mutty
   Naval Postgraduate School
   Monterey, California